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# Perspectives on the value of shared spectrum access

Final Report for the European Commission

Simon Forge, Robert Horvitz and Colin Blackman

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## Final Report

Support for the preparation of an impact assessment to accompany the Commission's Initiative on the Shared Use of Spectrum, SMART 2011/0017

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Prepared for European Commission, Information Society and Media Directorate-General, Electronic Communications Policy, Radio Spectrum Policy (Unit B4)

by

Simon Forge, Robert Horvitz and Colin Blackman

This report reflects the views of the authors and the opinions expressed here do not necessarily reflect those of the European Commission.

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# Preface

This report was prepared for DG Information Society and Media, Electronic Communications Policy, Radio Spectrum Policy (Unit B4) as the Final Report of a study to provide support for the preparation of an impact assessment to accompany the Commission's Initiative on the Shared Use of Spectrum (SMART 2011/0017).

The aim of the study was to contribute to a better understanding of the socio-economic value of shared spectrum access, including its impact on competition, innovation and investment. It is one of several inputs intended to support the European Commission's plans to publish a Communication on these issues. The report reflects the views of the authors and the opinions expressed here do not necessarily reflect those of the European Commission.

To carry out this assignment SCF Associates Ltd formed a project team of experts comprising Robert Horvitz (Open Spectrum Alliance), and Colin Blackman (Camford Associates) led by Simon Forge (SCF Associates Ltd), working on behalf of a contractual consortium led by SCF Associates Ltd (including DTI, GNKS-Consult, ICEGEC and RAND Europe).

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# Executive Summary

With demands on the radio spectrum becoming more intense, it is necessary to use this unique resource as efficiently and productively as possible. One way forward is to apply innovative and flexible authorization schemes like shared spectrum access.

"Shared spectrum access" includes all situations in which two or more users or wireless applications are authorized to utilize the same span of frequencies on a non-exclusive basis in a defined sharing arrangement.

This study,[1] therefore, is intended to contribute to a better understanding of the socio-economic value of shared spectrum access, including its impact on competition, innovation and investment. The study is one of several inputs supporting the European Commission's plans to publish a Communication on these issues.

This summary briefly presents the study's main findings and policy recommendations. A more in-depth description of these findings and recommendations is given in Chapter 5. The research, scenario analysis and economic modelling underpinning the study are presented in detail in Chapters 2, 3 and 4. This report reflects the views of the authors and the opinions expressed here do not necessarily reflect those of the European Commission.

## Objectives and approach

A key task for this study was to assess the net economic benefit of shared spectrum access for wireless broadband and its impact on mobile voice and data services, including roaming (Task 1). This was tackled through scenario analysis of the wireless industry to 2020 combined with economic modelling. As well as indicating the scale of the added value of shared spectrum access to the EU economy, the analysis explored concepts such as "Authorised Shared Access" (ASA) and "Light Licensing", highlighting the technical challenges, costs and incentives for incumbent users to adopt these concepts (Task 5).

A key input into the scenario analysis was a detailed review of ongoing industry developments, including research projects funded under the 7th Framework Programme, to assess future demands for spectrum (Task 2). This was done through a combination of desk research, expert interviews and a survey of relevant FP7 projects. Similar methods, including a survey of national regulatory authorities, were used to gather input from the 27 Member States on the current use of shared access for wireless broadband, indications of congestion in the 2.4 and 5 GHz bands, and the identification of candidate bands to avoid congestion (Task 3). Building on this information through further desk research and

[1] This report was prepared for DG Information Society and Media, Electronic Communications Policy, Radio Spectrum Policy (Unit B4) by a project team led by Simon Forge (SCF Associates Ltd), including Robert Horvitz (Open Spectrum Alliance) and Colin Blackman (Camford Associates) working on behalf of a contractual consortium led by SCF Associates Ltd.

expert interviews allowed estimates to be made of the impact on administrative costs to regulators arising from additional shared spectrum access (Task 4).

## Findings

The study team believes that increasing allocations of shared access spectrum for wireless broadband could provide a significant economic stimulus to the EU economy and bring additional social benefits to Europe's citizens. A quantitative assessment of the economic impact of increased shared spectrum access for wireless broadband was attempted as part of the study. The results are described in detail in Chapter 4. The basic assumption made was that more shared access is equivalent to extra spectrum and it is through exploiting this "new" spectrum that the major economic benefits of shared spectrum access accrue. The scenario simulations, which assumed allocation increases for wireless broadband of 200 and 400 MHz respectively, yielded estimates of the net economic benefit to the EU of shared spectrum access for wireless broadband and showed significant returns in net increases in GDP over nine years to 2020.

However, taking into account the range of uncertainties of this modelling and the margin of error in our calculations, the quantitative figures given in Chapter 4 should be considered as indicating the order of magnitude of the impact of shared spectrum access rather than an accurate prediction. Variations in results between the scenarios are due to the degree and forms of sharing, the bandwidth effectively available, and the costs of sharing including, in one scenario, extra licence-exempt spectrum and the refarming of some incumbents. The expansion of shared spectrum access may draw in new market entrants, services and business models. In consequence, sharing's effect is likely to have wide leverage, via increased competition, touching the majority of users through the rebalancing of existing tariffs as well as added capacity. It could have strong impacts on existing cellular mobile services, including roaming – data roaming especially.

Certain industry trends and developments form a set of drivers for increased sharing of Europe's radio spectrum. The first of these is the accelerating growth in wireless data traffic generated by smart phones, tablets, and other portable internet access devices. This fuels a need to expand cellular mobile networks rapidly (including backhaul) to accommodate an "exaflood" of data, a growing portion of which will inevitably be offloaded to shared access spectrum. Stronger integration between Wi-Fi and cellular, thanks to carrier investments in hotspots, handsets with diverse link options and easier handovers between technologies, may shift the balance of political support for licensed and licence-exempt allocations.

We also note an emerging "strategic partnership" between the cellular mobile and broadcast industries, as internet access from mobile devices becomes more attractive to the media sector. That may lead to new hybrid audiovisual services and an integrated vision of the UHF band's future. Meanwhile, the computing, consumer electronics and web services sectors of the ICT industry are now pushing for greater say over spectrum use and in particular for more unlicensed spectrum.

Our survey of national regulatory authorities (NRAs) found that their awareness of congestion in the shared access bands for wireless broadband is mainly anecdotal. Only one has measured occupancy of any of the five bands used by licence-exempt RLANs. Nevertheless, 11 NRAs report congestion at 2.4 GHz as increasingly widespread in the urban areas of their countries. Current and projected rates of Internet data traffic growth indicate that congestion will surely increase, although there is no consensus on an acceptable upper limit of Wi-Fi node density. The node density map of Europe reproduced in chapter 2 of this study shows that the Benelux countries have already reached the city of London's density but over a much larger area. If the number of Wi-Fi

nodes doubles in the next 5 years, as the Wireless Broadband Alliance predicts, and streaming video continues to expand its presence in licence-exempt bands, many more parts of Europe will experience congestion in the bands for shared access.

Thus there will be a need for more shared access spectrum. We consider an additional 300-400 MHz should be made available, including at least 100 MHz in new licence-exempt bands. We propose the bands identified in our second scenario (see tables in Chapter 4, or in short form in Chapter 5) and in our third scenario, where we also propose an additional licence-exempt band in the 500-600 MHz region and one at around 1400 MHz, each of 50 MHz.

With regard to the opening of bands for "white space" devices (WSDs), our survey of NRAs found strong interest in this idea as a way to increase spectrum utilization in predominantly licensed bands. Geo-database control of location aware devices is seen as a new tool of regulation with many potential uses. However, just 7 member states indicated that they plan to authorize WSDs in the UHF band, with 3 more undecided. That may be too few to support a robust market.

Our survey of FP7 research projects developing new radio technologies found that very few of them see any need to change shared access allocations for their technologies to enter the marketplace. But projects developing WSDs did favour rule changes to enable the deployment of their technology. A more general pattern emerging from the FP7 radio projects is the urgent need to replace static/rigid forms of spectrum authorization with dynamic/flexible ones.

We also found that "politeness" rules enable more sharing, by preventing interference, but they are also a source of inefficiency in channel use. Better coordination is needed between standards groups to improve compatibility between different new radio technologies.

If spectrum sharing increases, there will be new administrative burdens for NRAs. The costs are not significant, compared to other costs of sharing, such as infrastructure and sharing agreements, being estimated in the study to be some €35.8 million for Scenario 2 and about €45.8 million for Scenario 3. The implementation cost is estimated to be about €51.5 million for Scenario 2 and €84.7 million for Scenario 3. More importantly, the additional costs are less than the socio-economic benefits of sharing.

## Conclusions and recommendations

From the earliest days of radio, interference prevention has been a top priority, an unchallenged assumption guiding all spectrum management decisions. It remains the top priority today. But the opportunity cost of this policy is high: the underutilization observed in most frequency ranges now is the direct result of a century of commitment to guaranteeing licensees on-demand access to exclusively assigned, interference-free channels. Static rules dedicating radio resources to a single licensee, who may only need them from time to time, guarantee that the resources lie fallow the rest of the time. The gap between rights and needs is wide.

The combination of low utilization and the inability to accommodate new demand shows that the way spectrum is managed must become more adaptable and flexible. This need has been recognized for years. The Commission has responded by urging NRAs to replace overly specific allocations with converged generic allocations, like WAPECS and MFCN. However, any gain from changes at the allocation level will be minimal unless there are corresponding changes at the assignment level. Fortunately, the solutions are well known: channel pooling (as with cellular systems, trunking, etc), block assignments (common in the fixed service bands) and spectrum commons (bands without individually assigned channels).

It is now more important than ever that spectrum authorizations should not artificially increase scarcity. The Commission's recognition of the need to move away from exclusive and persistent channel assignments is reflected in a growing emphasis on shared spectrum access, which our findings support.

Our main recommendation is a move towards general authorization, through light licensing and de-licensing, as the Authorisation Directive requires. An earlier survey of NRAs found most of them willing to move in that direction "when a harmonised CEPT or EU approach is taken". In other words, this is an opportunity for regional leadership.

Authorized Shared Access (ASA) and Licensed Shared Access (LSA) combine elements of traditional "command and control" spectrum management with a market-friendly approach and innovative cognitive radio techniques. In that sense they offer a novel mix of old and new ideas about non-exclusive frequency rights. Since adaptive sharing is an improvement over exclusivity and static/persistent channel assignments, we see these proposals as appropriate in bands where special incentives and extra caution are needed to overcome the reluctance of incumbents to share spectrum – for example, in opening government allocations to new sharing arrangements with commercial secondaries.

Regulators might also consider modifying the conditions attached to licences in certain services so that channel or geographic exclusivity can be suspended if a regulatory review finds a licensee's utilization of their assigned spectrum is consistently below a level justifying exclusivity.

We also note the discussions in CEPT about recognizing the different needs of short-range devices (SRDs) and Wireless Access Systems including Radio Local Area Networks (WAS/RLANs) with regard to interference. This is entirely appropriate in light of our growing – and increasingly precarious – dependence on WAS/RLANs for access to the Internet. Much can be done to improve the operating conditions of WAS/RLANs in shared access spectrum without reaching the level of protection enjoyed by licensed services.

Going further, to accommodate future wireless broadband requirements in the light of the expected flood of data offloads from cellular networks, we recommend the creation of two new swathes of licence-exempt spectrum in the UHF region – above and below 1 GHz – of the order of 40-50 MHz each and reserved for WAS/RLANs.

We also believe it is time to move radio regulation in a new direction, gradually shifting responsibility for frequency and interference management from administrators to users.

The fundamental principle should be that everything is permitted which is not forbidden, rather than the principle which has ruled radio since its inception: that everything is forbidden except what is authorized by the state. If there is to be a transition from one mode of thinking to the other it must be evolutionary. Regulating shared access to spectrum, with progressively less restrictive technical conditions, is the way.

There is, unfortunately, a conflict of interest between the protection of incumbents and the accommodation of new spectrum users. To resolve this conflict it is not necessary to abandon the existing licensees, to throw open their channels and flood them with noise. What is needed is mutually agreed incremental expansion of allocations, in which interference-free channels are not guaranteed, where users accept responsibility for dealing with interference on their own, and where equipment suppliers have incentives to develop more "polite" protocols and robust equipment.

We envisage three policy options to promote greater access to shared spectrum, largely corresponding to our scenarios. These range from doing little or nothing, through a modest increase in shared spectrum access, up to embracing sharing fully, in order to

stimulate the EU economy, in particular by enabling wireless broadband to be rolled out with EU-wide coverage as quickly as possible.

# CHAPTER 1. Introduction: policy background and objectives

## 1.1. Policy background

The European Commission's overall radio policy objective is to maximize the socio-economic and environmental benefits of spectrum use. For a number of years, the Commission has sensed that a more flexible approach to authorization, based on general rather than individual rights, collective use of spectrum, service and technology neutrality and the least restrictive technical conditions, would reduce the cost of using and regulating communication services, increase efficiency and encourage innovation, thereby benefitting everyone who lives or works in the European Union. The elaboration of these principles has progressed in stages and the Commission now intends to move forward with a new emphasis on shared access to spectrum.

With this in mind, the Radio Spectrum Policy Group (RSPG) recently released a *Report on Collective Use of Spectrum (CUS) and Other Spectrum Sharing Approaches*.[2] In 2012 the European Commission plans to publish a Communication on the social and economic benefits of more flexible authorization procedures to enhance shared access to spectrum.

The next World Radio Conference (WRC) is also scheduled for 2012. A Communication from the Commission regarding WRC-12 notes the need for evidence that wireless broadband is a valuable and efficient use of spectrum as part of the EU's preparations for the subsequent Conference, WRC-15:

> The EU approach to WRC-15 should be based on a careful assessment of how efficiently the wireless broadband industry has used the substantial amount of spectrum made available through EU legislation, and on the societal and/or economic value the present services in those bands represent given the spectrum they occupy… The next WRC-15 agenda, which will be set in 2012, should address potential spectrum needs arising from important EU policies. In particular, it should include an item to respond to possible capacity constraints on the provision of wireless broadband in line with the aims of the Digital Agenda for Europe.[3]

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[2] http://rspg.groups.eu.int/_documents/documents/meeting/rspg26/rspg11_392_report_CUS_other_approaches_final.pdf (RSPG11-392 Final, November 2011),

[3] Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: The European Union's policy approach to the ITU World Radiocommunication Conference 2012 (WRC-12), Brussels, 06.04.2011 COM(2011) 0180 final, pp 9-10, http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/communications_et_al/com2011_0180_en.pdf

Therefore, one of the tasks assigned to this study is to assess the socioeconomic value and spectrum efficiency of wireless broadband in the context of shared spectrum access, and its contribution to Europe's Digital Agenda.

"Shared spectrum access" includes all situations in which two or more users or wireless applications are authorized to utilize the same range of frequencies on a non-exclusive basis in a defined sharing arrangement. "Shared access" is thus a broader concept than "collective use", which can be defined as radio frequencies allocated for use by an undetermined number of independent users with

- no limitation on applications or technology other than those required to avoid harmful interference;
- limitations on applications and/or technologies to reduce the risk of interference and maintain an acceptable quality of service;
- licensing or coordination to avoid interference to non-collective use applications or to facilitate future re-farming.

This definition of "collective use" merges elements from the Mott MacDonald study (Mott MacDonald, et al, 2006) and the RSPG's Final Opinion on CUS, because "shared access" includes just those elements, along with any other possibility for multiple users to access the radio spectrum without exclusive rights.

"Shared access" thus encompasses licence-exempt bands, bands shared by licensed and licence-exempt applications, and licensed and light-licensed "commons". Potentially important new kinds of "shared use", not covered by "collective use", are emerging from discussions about "Licensed Shared Access" (LSA) and cognitive access to "white spaces" in the UHF band.

## 1.2. The objectives of the study

This study is intended to contribute to a better understanding of the socio-economic value of shared spectrum access, including its impact on competition, innovation and investment. The work presented here builds on previous work to further advance the Commission's knowledge in this area. It is one of several inputs supporting the European Commission's plans to publish a Communication on these issues.

The specific tasks of this study were:

**Task 1:** Assess in qualitative and if possible quantitative terms the net economic benefit of applying shared spectrum access for wireless broadband, and its socioeconomic impact on traditional mobile services like voice and data transmission, including the take-up of roaming services. Perform these tasks with a focus on the impact in the next 5 years.

**Task 2:** Review ongoing industry developments as well as projects under the 7th Framework Programme in order to assess:

- if existing frequency allocations for shared spectrum access will be able to satisfy the estimated demand for spectrum resulting from the projects;
- quantify whether technical usage conditions of the existing frequency allocations for shared spectrum access need to be changed, in order to facilitate the use of innovative spectrum sharing techniques and identify which usage conditions, such as "politeness" rules or mitigation techniques, are considered necessary to maximize the socioeconomic value of the applications in the band;

- quantify the need for any additional spectrum for shared spectrum access and the socio-economic value of this spectrum.

**Task 3:** Gather input from the 27 Member States on current use of shared access frequency allocations for wireless broadband, in particular assess the intensity of Wi-Fi use in the 2.4 GHz and 5 GHz bands. Furthermore provide indications of possible congestion that could hamper the further take-up of wireless broadband, and possible candidate bands to avoid congestion.

**Task 4:** Quantify, as far as possible, any administrative cost which would be created or saved if additional spectrum was made available for shared spectrum access based on the findings of Task 2, 3 and 5. Furthermore assess and quantify as far as possible, implementation costs in relation to candidate bands identified under task 3.

**Task 5:** Identify key bands targeted by proponents of concepts such as "Authorised Shared Access" (ASA) and "Light Licensing", outline the principal costs and technical challenges to be addressed if those bands were to be allocated for such an approach, and identify the incentives for incumbent users in those bands to agree to the adoption of these concepts.

## 1.3. Structure of this report

The remainder of this report is structured as follows:

- Chapter 2 sets out the nature of the problem facing spectrum policy. Demand for high-bandwidth spectrum is escalating as Europe's citizens turn to the wireless internet to deliver the social and economic services that are increasingly essential for modern living. At the same time, the spectrum policy of the past has resulted in misallocation that has led to artificial scarcity. The chapter explores the problems in detail.

- Chapter 3 looks in detail at how we can improve spectrum utilization through shared access. It explores the changes in technical conditions that are necessary to enhance shared spectrum use. New authorization classes, such as light licensing, underlays and Authorised Shared Access, are outlined, and ways of harnessing the benefits of coordination and cooperation are explored. The possibilities of repurposing and refarming are examined, with a focus on cellular mobile and broadcasting. The chapter concludes by considering the evolving role of the regulator.

- Chapter 4 compares different options for sharing through an econometric model, based on three scenarios of evolving shared use. This shows how the extent of shared use might impact the EU economy in qualitative and also quantitative terms, of GDP and employment and also the social benefits. The chapter proposes potential bands for shared use, and identifies bands that should remain exclusive allocations. The impacts of shared use on the traditional mobile industry, and its services, as well as on the administrative costs for spectrum management are also explored.

- Chapter 5 summarizes the findings of the study by task and presents the study's conclusions.

**Terminology**

**Authorization** is a right granted by a regulatory authority permitting the operation of a radio station, radio application or electronic communication service in conformance with national laws and prescribed technical conditions.

**Assignment:** When a regulator authorizes the use of a specific radio channel by a station or group of stations under specific conditions, usually by issuing a licence, this is termed an "assignment". Thus a radio channel may be "assigned" to a station.

**Allocation:** When a regulator registers a band for use by one or more radio services under specified conditions, this is termed an "allocation". (It is important to note that channels are assigned to radio stations, while bands are allocated to radio services.)

A **"licence"** is a document issued by the relevant authority authorizing the use of a radio station or equipment and/or radio frequencies to provide electronic communication services under standard conditions (a class licence), or authorizing the construction, ownership and exploitation of an electronic communication network or service when the number of such networks or services must be limited and specific conditions of use are attached (individual rights of use).

A **"station"** is a radio transmitter or receiver – or a combination of these – including accessories like antennas, power supplies, etc., at a single location which provides a radio service.

A **"radio service"** transmits or receives radio waves for a defined telecommunication purpose.

A **"channel"** is a span of adjacent radio frequencies. When a regulator authorizes the use of a radio channel by a station or group of stations under specific conditions, usually by issuing a licence, this is called "assignment".

A **"band"** is a set of radio channels or a span of adjacent radio frequencies allocated for the use of one or more radio services.

A **"user"** is any legal or natural person utilizing a wireless application based on some form of authorization.

**"Shared spectrum access"** includes all situations in which two or more users or wireless applications are authorized to utilize the same range of frequencies on a non-exclusive basis in a defined sharing arrangement, along with any other possibility for multiple users to access the radio spectrum without exclusive rights.

**"Co-existence"** is when the operation of a radio system is capable of impairing the operation of another radio system but it does not. The European Conference of Postal and Telecommunications Administrations (CEPT) uses "co-existence" in a more specialized sense: co-existence is successful when two systems operate in adjacent frequency bands with acceptable impact on each other's operation. Similarly, **"sharing"** is when two radio systems use the same frequency band with acceptable impact on each other's operation.

**"Spectrum occupancy"** is measured as the percentage of time that the energy observed in a given radio bandwidth is above a certain threshold. If that threshold is near to, but above, the noise floor in a band with licensed users, and impulse noise is not present, energy above the threshold can be taken as an indication of the presence of radio signals.

**"Spectrum utilization"** adds a geographic dimension to "spectrum occupancy". The concept is summarized by this formula: Bandwidth x Space x Time. But there several ways to translate that into a specific measure. In some contexts "space" has a 3-dimensional interpretation, but in others it is 2-dimensional, when the area assigned to a transmitter or receiver matters more than height.

**"Congestion"** means that the intensity of transmissions in a band of radio frequencies has reached a point where transmissions of the same type degrade each other's channel quality, by reducing range or throughput or by increasing contention or interference, and any further increase in transmissions will further degrade the existing systems' operation. "Congestion" can be localized or pervasive.

**"Saturation"** is an extreme form of band congestion where additional transmissions cannot be accommodated without causing a loss of service to some existing users.

# CHAPTER 2. Spectrum: misallocated, not scarce

## 2.1. A more spectrum-efficient Europe

Europe's citizens are replacing their basic mobile phones with smart phones and tablets. As well as making voice calls they want to check email and surf the web, everywhere and at any moment. Increasingly they want to stream music, watch movies, download books and play games with other users, without having to bother about whether their connections are wired or wireless. In other words, the always-connected lifestyle has arrived and a rapid roll out of ubiquitous affordable broadband is needed for the well-being of EU citizens. Wireless technologies will be essential to fulfilling the Digital Agenda. Cloud computing is also widely expected to take off over the next few years, placing even more pressure on the radio spectrum. With limits on the spectrum available to meet growing high-bandwidth demands, a key question now facing Europe is:

> *Can more shared spectrum access increase the benefits of wireless broadband and support social progress and economic growth?*

To begin to answer this question, this chapter sets out the nature of the problem facing spectrum policy (section 2.2) and considers how greater efficiency could be achieved through sharing (section 2.3). The chapter then explores the dimensions of sharing (in section 2.4) with the various mechanisms. The chapter then looks at the constraints on sharing, including congestion (section 2.5). Trends and industry developments, including IMT-Advanced, affecting demand for spectrum are considered in section 2.6. The impact of IMT-Advanced and other technologies on the future radio landscape are described in section 2.7. The European market for wireless broadband and the impact on spectrum sharing is examined in sections 2.8. Finally, the impact on future demand for spectrum resulting from emerging technologies is reviewed through an examination of relevant FP7 projects.

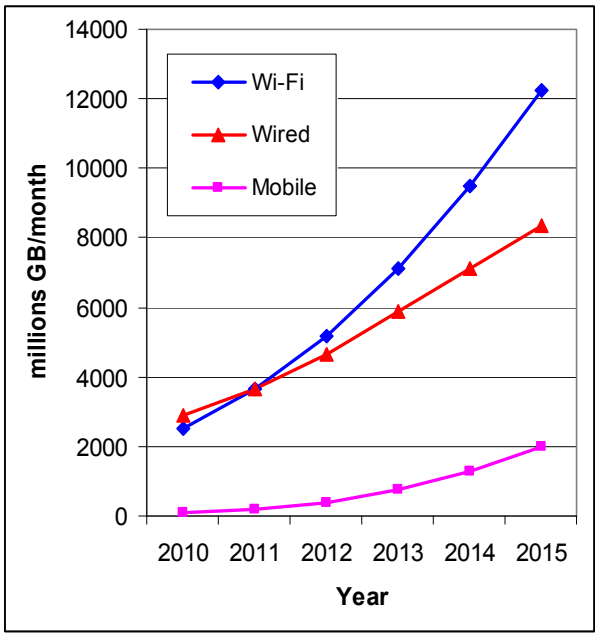
### 2.1.1 The broadband factor

Broadband is increasingly recognized as the strongest economic growth stimulant of all information and communication technologies (ICTs). There are several estimates of the effects, one of the most optimistic being that of World Bank economist Christine Zhen-Wei Qiang, who estimated that "for every 10-percentage-point increase in penetrations of broadband services, there is an increase in economic growth of 1.3 percentage points" (Qiang, 2009). Other estimates are much lower, down to 0.08%.

Wireless networks make at least three special contributions to the socioeconomic value of broadband: the first is by enabling mobile access, something wired media cannot do. The second is by supplying connectivity at much lower cost per user in low-density situations (eg in sparsely populated regions). The third is by eliminating the need to rewire when network configuration changes, thus facilitating adaptable and ad hoc deployments. Even in situations where wireless connectivity is not essential, it is often the preferred solution, which makes it increasingly popular, particularly for self-deployed networks. In Europe

there are already more wireless than fixed broadband subscribers; data traffic has surpassed voice on mobile networks; and the total volume of wireless data traffic overtook wired data traffic in 2011. Therefore, we can say that most of the socioeconomic value of broadband now comes from wireless media, and as Figure 2.1 shows, most broadband data now reaches end-users through shared access spectrum.

Figure 2.1. European internet data traffic forecast by medium, 2010-2015




Source: Cisco (2011)

However, the broader aim of this study is to consider the potential for improving utilization of the radio spectrum by enhancing shared access, and to assess the economic and social benefits of doing so.

Enhancing the availability of frequencies for shared access will require a more flexible approach to regulation than is current practice. A starting premise for this study is that radio frequencies are not inherently scarce. Rather, scarcity results from an allocations framework which does not adapt quickly to changes in demand for radio services and from regulations which limit emissions to protect the availability of interference-free channels on pre-determined frequencies for licence holders. That demands for spectrum allocations to support new services are difficult to meet even while current utilization rates are low, indicates that something is wrong with the way we manage spectrum.

The gap between a regulatory framework which favours static channel assignments and persistent usage rights, on the one hand, and the dynamically variable character of actual communication needs on the other, is widened by the tradition of authorizing communication infrastructures to be owned and operated by a single licensee or dedicated to a single purpose, application or profession. The result is that many channels and communication systems, used only intermittently, are permanently reserved for a small number of users. Idle resources are not available to any other service or user, even in bands where the allocation is shared. Consequently, any gain from increasing sharing at the allocation level will be limited unless methods are also agreed to increase the sharing of frequencies, channels, and infrastructures within the slower-evolving framework of band allocations.

Our study is focused on the main drivers – the capture for Europe of increased economic and social benefits from shared spectrum access. Increasing spectrum utilization is more than an engineering problem. Priorities and values are important, too, and there is an unavoidable tension between increasing spectrum utilization and protecting access to interference-free channels for licensees. It is basically a conflict of interest between incumbent and prospective users of the radio spectrum. The "first come, first served" policy of traditional spectrum management defies continual re-optimization of spectrum use policies to serve today's and tomorrow's needs.[4]

Much of the equipment in Europe's radio systems has been in service for 25 years or more. Even though spectrally inefficient by contemporary standards, government commitments to interference protection still apply, with more and greater sums still to be spent on the switchover to digital TV, the expansion of cellular networks and the launching of new satellites. Billions of Euros have been invested in wireless networks to support safety-of-life and national security as well as essential services such as air traffic control, environmental monitoring and maritime navigation, which must not be exposed to harmful interference. However, protecting the inefficiency of an aging radioelectronic infrastructure has a cost, and so our study is aimed at revealing the options on a technical and economic basis for a more spectrum-efficient Europe.

## 2.2. What's wrong with exclusive allocation?

Exclusive spectrum allocation has been our heritage since the start of the 20th century when the public airwaves were divided into frequency bands for different services. Stations in each service were expected to fit a certain profile, aspects of which are now specified by regulations (national or international), defined as standards (by bodies like ETSI), or adopted voluntarily by users.

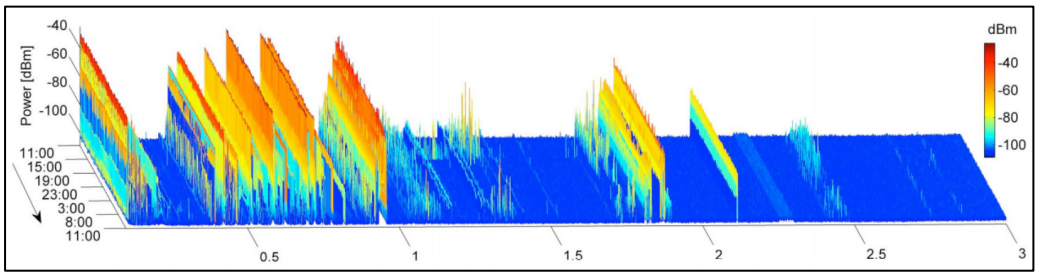
Grouping stations into services with different profiles and separate frequency bands made it easier to design compatible equipment, anticipate traffic patterns and devise band plans. It also became possible to agree on interference protection as appropriate. Not all applications are equally affected by unwanted signals: RF noise from dialysis machines might block radio-telescopes locally but have no effect on weather radars.

Band allocation is more than an assessment of system capacity requirements. It is also a value judgment about the service's contribution to society, relative to competing services, and its future value to society. When society, the economy and technology are changing rapidly and in steps large enough to be felt as surprises and dislocations, it is inevitable that a band allocation will either be sub-optimal now (so as to meet future requirements), or optimal now, destined to become sub-optimal soon. Thus the average spectrum utilization rate in Europe is under 10%.[5] That is sub-optimal by any definition.

[4] Vice-President Neelie Kroes (2010) touched on this in her speech to the EU Spectrum Summit: "We should assume nothing beyond the need to maximise the social, economic and environmental value that spectrum can be used to generate… I am keen to avoid newer and better technologies being at a disadvantage simply because they came later…"

[5] See, for example, Lopez-Benitez, *et al.* (2009); Wellens, (2007); and CRFS, (2009).

Figure 2.2. Radio channel occupancy
24-hour cycle near Brno, Czech Republic, July 2008




Source: Valenta, et al (2010).

In the band scan in Figure 2.2, it can be seen that the spectrum below 1 GHz is more intensively used than the spectrum above 1 GHz, except for the cellular mobile bands near 2 GHz and, to a lesser degree, the licence-exempt band at 2.4 GHz. Note, too, the inactivity at 225-400 MHz (near the left end of the spectrum): those "beachfront" frequencies are reserved for military use. Similar band scans were made in the centre of Paris and the pattern of frequency use was found to be similar: average occupancy of the 400 MHz-3 GHz band was 6.5% in Brno and 7.7% in Paris (Valenta, 2010).

Band scans like these may not catch signals from short-range devices, systems with directional antennas aimed away from the monitoring site, or military signals designed to escape detection. So the overall level of spectrum utilization could be understated. More to the point, with static channel assignments, there needs to be "headroom" to accommodate the fact that peak traffic requires more capacity than average traffic. But when that headroom is many times greater than the average occupancy, assigned channels are not be the most efficient way to ensure on-demand access.

## 2.3. Who does sharing affect and how?

With channel occupancy measured at less than 10%, the current pattern of spectrum use must represent something more than a series of misjudged service requirements. We believe it indicates a systemic problem: inflexibility in a time of rapid change. This diagnosis is not original. We are simply adding our voices to an already substantial chorus of critics who note that idle channels in specific bands matter less than the fact that society as a whole suffers when bottleneck resources are used inefficiently.

The high cost of mobile licences at auction, for example, can be partly blamed on the continuing allocations of frequencies to services in which utilization rates are very low.[6] If IMT-Advanced (more commonly known as 4G cellular) claims to need something like 1 GHz of additional spectrum to support growing demand from mobile subscribers, and the cost of that spectrum is similar to the recent average auction price for frequencies around 2 GHz (€0.65/MHz/pop),[7] then the total cost of the additional needed spectrum could be

[6] A dramatic illustration of the wastefulness of current allocation processes is found in the 870-876 MHz and 915-921 MHz bands. These were allocated to PMR/PAMR in 1996 and were completely unused for 15 years. They are adjacent to the GSM-R bands at 876-880 MHz and 921-925 MHz, and partly adjacent to the GSM bands at 880-915 MHz and 925-960 MHz, where they could have been more usefully employed. They will soon be made into shared access spectrum for RFID and other short-range devices, including wireless alarms and utility telemeters (ETSI, 2008-09).

[7] Sims, 2011. The quoted price actually represents a decrease from earlier levels as market participants believe Europe is taking steps to release more spectrum.

about €320 billion. In the conventional cellular business model, all of this would be recovered from the subscribers. In other words, many might end up paying for the inefficiency of other services' spectrum utilization.

### 2.3.1 Exclusivity and sharing in Europe today

The state of exclusivity and sharing today is recorded in the European common allocations table, which shows that it is now normal for different services to share frequency bands (ERC, 2011). Indeed, very few bands still have exclusive allocations. How few? As far as we can tell, only 0.8% of the European common allocations table consists of exclusive allocations – about 2.3 GHz out of 275 GHz. If one considers only the spectrum below 3 GHz, then about 335.5 MHz is exclusively allocated (11.2% of 3 GHz).

Others may disagree, but we think the following situations should not be considered band-sharing, but rather treated as exclusive allocations. If these situations are considered sharing, then there is even less exclusive spectrum than estimated:

- Bands allocated to two or more services to enable them to intercommunicate (eg the harmonized military band at 225-400 MHz, which combines air, sea, land and satellite links; the Amateur and Amateur-Satellite Services at 47-47.2 GHz; or the band for Digital Audio Broadcasting at 1452-1492 MHz, which combines sub-bands for terrestrial and satellite transmissions).
- Frequencies allocated to one radio service which short-range magnetic induction devices may also use (eg the sound broadcasting band at 526.5-1606.5 kHz: certain types of animal tags and medical implants use these frequencies as well, but not to emit radio waves into free space).

Another large group of allocations, which could be considered either shared or exclusive, depending on one's definition, is the 20.3 GHz for radio astronomy, earth observation satellites and passive space research. These services often use the same bands because they share the characteristic of only absorbing radio energy, and they each need total radio silence to fulfil certain missions. Passive scientific research might be considered a single "meta-service" but, separate or united, ITU RR footnote 5.340 forbids all emissions in a long list of bands allocated for their use. Those bands cannot be shared with communication services – even though it might be physically possible, if the exclusion zone around sensitive facilities is large enough.

Over 75% of today's exclusive allocations are for various types of radar, mainly military. Table 2.1 lists the largest unshared bands in descending order of size, with comments on current usage. A deeper discussion of sharing possibilities in these bands is in Chapter 3.

Radar allocations in this table were made before efficient use of spectrum was as important to policy makers as it is today, and when the technology available was not as advanced as now. Indeed, the Cave Independent Audit of Spectrum Holdings for the UK Government described some military radars as "quite profligate in their use of spectrum… it should be possible to replace some radars with new designs that meet their requirements (including foreseeable needs for improvement) with reduced spectrum occupancy" (Hulbert, 2005). So it is not inappropriate to question whether the existing allocations and deployments reflect current thinking on efficient use of spectrum. Information about the age and costs of existing deployments, and about alternatives capable of meeting performance requirements, is not readily available.[8]

[8] However, WIK Consult's 2008 study for the Commission on optimizing the public sector's use of spectrum includes a chapter on "improvements in radar technology" to enhance band sharing opportunities.

Table 2.1. Frequency ranges of the largest unshared bands

| Frequency band | Service | Comments |
|---|---|---|
| 15.7-16.6 GHz | Radiolocation | "Harmonized military band for land, airborne and naval radars… identified for major military utilization [but] can be shared between civil and military users according to national requirements and legislation." According to *ITU footnote 5.512*, 15.7-17.3 GHz was "also allocated to the fixed & mobile services on a primary basis" by Austria, Finland, Montenegro, Serbia & 42 non-European countries at WRC-07. |
| 33.4-34.2 GHz | Radiolocation | "Harmonized NATO band… motion sensors; short-range radar; surveying and measurement". *Recommendation ITU-R M.1640* gives detailed information for sharing and compatibility studies to protect the radars and other sensors that use this band for "mapping, target identification, …aim-point determination, test range instrumentation, etc." |
| 47-47.2 GHz | Amateur | Terrestrial and satellite amateur radio. Primarily for weak-signal experiments, this band is still lightly used. |
| 240–322 MHz | Mobile | *Footnote EU10:* "The mobile service in the harmonized military band 225-400 MHz generally comprises land, air, maritime & satellite mobile applications." There are under-used channels in this band, but as it is home to major NATO and Russian military communication networks, it might be considered too politically sensitive to share. |
| 15.63–15.7 GHz | Aeronautical Radionavigation | Current allocation is for "Doppler radar low power sensing" and "ground movement radar". The latter transmits brief pulses in very narrow sweeping beams to detect and track vehicles on air field surfaces. Agenda item 1.21 at WRC-12 is to consider extending the primary Radiolocation allocation at 15.7-17.3 GHz to include 15.4-15.7 GHz while protecting current uses. |
| 1559 – 1610 MHz | Aeronautical Radionavigation Radionavigation-Satellite | This band supports 3 global positioning satellite systems – GPS, Galileo and GLONASS – operating space-to-earth in adjacent sub-bands, along with space-to-space links. Given the weakness of received GNSS signals, especially indoors, and the growing number of applications dependent on them, sharing with additional services in this band could jeopardize existing socioeconomic benefits. |
| 335.4–380 MHz | Mobile | *Footnote EU10:* "The mobile service in the harmonized military band 225-400 MHz generally comprises land, air, maritime and satellite mobile applications." Part of a major NATO/Russian military band, it might be too politically sensitive to share. |
| 1452–1492 MHz | Broadcasting, Broadcasting-Satellite, Fixed, Mobile | Four services share this band as co-primaries, but in most CEPT member states it is designated for satellite & terrestrial fixed & mobile sound broadcasting using DAB. DAB uptake has been disappointing, so the future of this band is under review. |
| 1626.5-1660 MHz | Mobile-Satellite | Allocated on a primary basis to IMT cellular for earth-to-satellite links, CEPT is studying the implications of complementary ground stations mediating those links, as such stations could interfere with radio astronomy and navigation satellites using the 1610-1626.5 MHz band (ECC Report 165). |
| 117.975-137 MHz | Aeronautical Mobile (R) | The main band for air/ground voice communications used at all airports and air traffic control centres for en-route, approach and landing phases of flight. Flight safety considerations make it risky to share with other services. |

Most bands exclusively allocated for use by radars in Europe are above 15 GHz. The bandwidth potentially available for sharing is large, but that range of frequencies is only suitable for a few types of communication systems, most notably fixed point-to-point links, satellites and high-capacity short-range (indoor) "hotspots". Demand for additional spectrum is increasing from those applications, but the radar bands cannot fulfil Europe's main need, which is for more regionally harmonized spectrum for mobile broadband.

Sharing in other currently exclusive bands (the 23.2% not used by radars) may be possible as well, although the amount of spectrum available in those other bands is not large and

safety and security needs must be taken into account. The inventory of current spectrum utilizations proposed in the RSPP would help identify which bands are the best candidates for more shared use, and whether the sharing should be geographic, temporal, frequency or power-limited, or based on other strategies.

## 2.4. Alternatives to exclusive allocation

There are basically two alternatives to exclusive allocation – "flexible use" and shared allocations.

In the traditional approach to spectrum management, limitations on services in a shared allocation tend to be much tighter and more carefully defined than services with exclusive allocations. This is shown in the sharing and compatibility studies which precede co-existence decisions.[9] Such studies are needed because interactions between systems differing in type are pair-specific, more complex and unpredictable than interactions between systems of the same type. Systems in different services might also be unable to communicate with each other, reducing opportunities to coordinate their band use and avoid mutual interference. If the compatibility studies identify potential problems, geographic restrictions, frequency coordination, power output limits, stricter emission masks, duty cycle constraints, special antenna patterns, etc, might be required. Such "static sharing can result in a significant proportion of spectrum being unusable at any given location" (WIK, 2008).

The point is that increasing spectrum utilization through more intensive sharing within the framework of traditional spectrum management can lead to stricter service limitations – to less flexibility, in other words – as well as "buffers" of unusable resources. Since we believe that inflexibility makes spectrum use less efficient, a better option is to move beyond the framework of traditional spectrum management, toward more flexible use. As indicated above, the problem is not with exclusive allocation – a condition which is rare now. In our view, the problem is in the rigidity of service-specific allocations, single-purpose infrastructures and static channel assignments.

This first factor is already well recognized, as many Commission policy statements have argued for service neutrality (see the discussion of WAPECS, below).

The second factor is pushing its way onto the regulatory agenda with demands for a huge increase in the spectrum allocated for the next generation of cellular mobile networks. It may be that the only way these networks can be accommodated is by displacing many individually licensed, single-purpose infrastructures. Since we criticized these systems earlier for keeping large swathes of spectrum underutilized, getting rid of them should be a good thing. However, that entails expanding the influence of a relatively small number of firms, reducing competition, diversity and choice in wireless services. The challenge posed by the expansion of cellular networks is that while they do offer a scalable, multi-purpose infrastructure, the gain in efficiency of spectrum use has a high price. That price is a consolidation of power and control over "bottleneck" resources.

The third factor, static channel assignments, has proven alternatives in block assignments, with channel use coordinated locally by networks (as with cellular and trunked systems), and in spectrum commons (bands of unassigned frequencies). Whatever the model, the pooling of frequencies corrects the problem of channels kept idle by regulation, a policy

[9] "Sharing" refers to the coexistence of different services within the same band, while "compatibility" refers to coexistence between services in adjacent bands.

which deprives the user community of resources in order to ensure individual access at times of peak demand. Pooled channels are the essence of "shared access spectrum".

### 2.4.1 Service/technology neutrality and flexible use

The history of spectrum management is one of service and technical non-neutrality. Detailed hardware specifications and limits on the purposes for which systems may be used are hallmarks of the "command and control" approach. What flexibility is available to a radio spectrum user is controlled by technical conditions attached to the authorization.

In 2005 the Commission presented a bold new "wireless access policy for electronic communications services" (RSPG, 2005). WAPECS was motivated by the belief that we were rapidly approaching a time when any communications service might be offered via any platform so only a radically simplified, broadened and generic regulatory policy would be "future proof" in the face of the continuing flood of overlapping service concepts, new wireless standards and convergent/hybrid technologies. Some also believed that making conditions of band use less specific to individual frequency ranges would increase the competition between delivery systems, to the benefit of users, and enable faster introduction of innovative services and technologies. WAPECS became the focus of the Commission's effort to coordinate a region-wide shift in spectrum policy toward technology- and service-neutrality and "flexible use" allocations.

An important aspect of the 2005 WAPECS Opinion was the decision to introduce this approach gradually. Constraints on the pace of change, and justifications for maintaining differentiated regulation, came from many quarters: international agreements, technically specific and long-lasting licences, the risk of interference into adjacent bands, protection for services pursuing "general interest objectives" (public broadcasting, emergency response, scientific research, etc). The EU's policy that a band once harmonized should stay harmonized was also a factor: change of use by a Member State is inappropriate for harmonized bands even if the aim is introducing greater flexibility.

Another reason for caution was a paradox mentioned in ECC Report 80 (2006) which is still not well understood: "introducing more flexibility in the management of a particular frequency band generally results in imposing new constraints on the systems in that band, ie limiting their flexibility in using spectrum".[10] In other words, there seems to be a trade-off between flexibility in band management and flexibility in band use.

A more fundamental problem is that flexible use makes it impossible to create a stable definition of "harmful interference", since one cannot be sure what the victim service will be (RSPG, 2005b). Even before WAPECS, defining harmful interference was difficult. After WAPECS, it became impossible – and yet crucial, thanks to the Framework Directive, which said, "This basic concept of harmful interference should therefore be properly defined to ensure that regulatory intervention is limited to the extent necessary to prevent such interference".[11] With WAPECS, uncertainty due to service neutrality led to the notion of tradable or negotiable interference rights. So the need to define harmful interference devolved to specific situations: in exchange for greater freedom, users take on more responsibility for dealing with interference.

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[10] ECC (2006), page 11. This may be related to another inverse relationship noted by Isabel Neto in her study of Wi-Fi in Africa: "more relaxed licensing regimes have, on average, more restrictive conditions placed on power and range". Neto, I. (2004) Wireless Networks for the Developing World: The Regulation and Use of Licence-Exempt Radio Bands in Africa, http://itc.mit.edu/itel/students/papers/neto_thesis.pdf

[11] Framework Directive (2002, 2009), paragraph 31, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0140:EN:NOT

The Member States suggested candidate bands and these were identified for WAPECS:

- 880-915 MHz, 925-960 MHz, 1710-1785 MHz and 1805-1880 MHz (designated for GSM);
- 1900-1980 MHz, 2010-2025 MHz and 2110-2170 MHz (designated for UMTS);
- 790-862 MHz (the "digital dividend" band, soon to be open for mobile/fixed communications networks);
- 2500-2690 MHz (mobile/fixed communications networks including IMT)
- 3400-3800 MHz (mobile/fixed communications networks and satellites).

In 2010, CEPT surveyed administrations about their experiences implementing WAPECS, but it was too soon: "the practical effect of the WAPECS principles on industry and consumers is not yet fully apparent… national implementation is not really already in place…" (CEPT, 2010). When known, the impact of WAPECS could confirm or refute the hypothesis that rigidity in regulation is the root cause of inefficient spectrum use.

The concept of "flexible use" has already spread beyond WAPECS anyway. Recast as the "least restrictive technical conditions" (because the least restrictive technical conditions enable the most flexible use), "flexible use" has become a "co-primary" principle, along with harmonization, in EU spectrum policy.[12] Distinguishing between harmful and tolerable interference, CEPT has suggested the introduction of "interference trading where the different operators negotiate coexistence conditions including possible compensation payments…" (ECC, 2006). The possibility of trade in interference rights and sharing rules directly negotiated by the band users themselves shows how different "flexible use" bands are from the norms of traditional spectrum management.[13]

Another distinctive feature of "flexible use" is little or no regulator involvement, and no need for administrative procedures, when changing a band's usage. The goal of replacing "command and control" with "flexible use" is emphasized in a Communication from the Commission in 2007:

> a flexible, non-restrictive approach to the use of radio resources for electronic communications services, which allows the spectrum user to choose services and technology, should from now on be the rule, as opposed to the restrictive approach which is often still used today. Measures which deviate from the new approach may still be taken, but must be duly justified (eg for public safety and security) and take into account their impact on innovation, competition, investment and social value. Furthermore, within the scope of 'electronic communications services' as defined in the Framework Directive, exclusive use by a particular service, such as mobile or broadcasting, should be removed (European Commission, 2007).

[12] "Rapid innovation has created a need for speedier access to spectrum for individuals and service providers than is possible under traditional methods. This points to the need for greater flexibility in the management of spectrum resources for wireless electronic communications, while maintaining harmonisation where necessary." – RSPG public consultation on WAPECS, p 1.

[13] Even though the development of a regulatory framework for licence exempt white space devices has not been characterized by a search for the "least restrictive technical conditions" or flexibility with regard to interference, the 470-790 MHz band is now "being investigated for the implementation of more flexibility" according to the WAPECS page on Europe's Information Society thematic portal, http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/topics/ecs/wapecs/index_en.htm

### 2.4.2 Estimating sharing opportunities today

*If spectrum isn't being used everywhere, all the time, there's an opportunity for sharing.*[14]

The ITU recommends a quantitative method for analysing the frequency use and deployment distribution of existing radio stations to identify gaps where new services and stations could be accommodated (ITU, 2007). However, they acknowledge that "limited use is in practice made of quantitative methods of finding the best assignments that will lead to the most economical use of the spectrum…". Their method, they admit, is "laborious". It requires extensive information collection and the resulting estimate is crude.[15] Instead, many NRAs rely on "heuristic methods, together with individual empirical data indicating the probability of harmful interference between radio stations".[16] So while there is a method recommended by the ITU for assessing the availability of spectrum-space for new uses in currently occupied bands, it is not used much because of its limitations and information collection requirements. Better tools need to be devised for this important task, or alternatively, greater flexibility must be granted to the users of spectrum so that innovation and efficient utilization are not constrained to the extent that they are today.

### 2.4.3 General principles, mathematical models and "rules of thumb"

The need to expand band sharing has led to a search for general principles and "rules of thumb" enabling regulators to predict which services are likely to be compatible and which are likely to clash. Today it is widely appreciated that generalizations about sharing are risky when details can defeat them and it is so difficult to fix a flawed policy decision. In a "command and control" regulatory regime where allocations persist for years, authorizing new sharing arrangements requires careful analysis by experts who are familiar with the details of the services, how they operate and how they evolve.

What happens when different radio systems share a band of frequencies can be modelled mathematically and assessed either statistically or deterministically. The deterministic approach is to calculate link budgets for both systems and compare the strengths of an interfering and a victim signal at specific times and places. Such calculations are often based on "worst case" assumptions, in order to establish an upper limit on the strength of the unwanted emissions. But that says nothing about the likelihood of the "worst case" occurring. For that, a statistical approach is needed (eg with "Monte Carlo" techniques), modelling both victim and interfering systems to see how the effects vary as assumptions change, to identify the most relevant variables and build up a picture of the probability and severity of interference (ERC, 2002).

While the deterministic approach highlights "worst cases", the statistical approach shows what is "likely". Spectrum managers use both methods to anticipate and foreclose the possibility of harmful interference – so both tools for compatibility assessment tend to be used with a conservative agenda. Neither is intended to maximize spectrum utilization.

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[14] Quote from Paul Kolodzy, speaking at the 12th Annual International Symposium on Advanced Radio Technologies (ISART, July 2011), whose theme was "Developing forward-thinking rules and processes to fully exploit spectrum resources".

[15] The crudeness of the results is acknowledged by the ITU, which notes in their Recommendation that "practically no account is taken of the time parameters of emissions. In particular, continuous signal modulation parameters and class of emission data are completely lost. Pulse signals are treated as continuous…". Thus, their method cannot validate dynamic sharing arrangements.

[16] Quoted from the preamble to ITU-R SM.1599-1.

## 2.5. Understanding the dimensions and mechanisms of sharing

### 2.5.1 A taxonomy of sharing models and techniques

Even before radio emissions could be limited to narrow frequency bands in order to be separated by tuning, it was recognized that spectrum sharing is fundamentally different when systems compete and when they cooperate. Competition implies users acting selfishly to maximize their own benefits even if others are thereby deprived, a behaviour which clearly discourages sharing by increasing the risk of costs being incurred without benefit. Deliberate jamming is the most extreme type of competitive spectrum use, illegal in most contexts.[17]

Cooperation, on the other hand, makes sharing easier because it creates opportunities for jointly maximizing the benefits and reducing the risks and costs of resource use. The most striking example of the benefits of cooperative spectrum use is in wireless mesh networks, where nodes relay traffic for each other and which can, in the right configuration, attain a greater throughput collectively than is possible through any individual link. It is possible to design cooperative behaviours into radio equipment now so they occur automatically and no longer depend on the goodwill or skill of the operator.

Of course, radio users can compete and cooperate at the same time, or coexist neutrally, for their behaviour towards each other does not have to be either simple or uniform. We understand neutral coexistence to mean that systems do not actively coordinate their use of spectrum.

A prerequisite to both cooperation and competition is awareness of the presence of other systems in the same set of frequencies. This awareness can come from feedback within one's own system – eg failure to receive an acknowledgement that a transmission has been received can be taken as evidence that interference has occurred – or from outside the system, as when a cognitive radio actively scans channels to discover nearby signals. Neutral coexistence is equivalent to a lack of awareness of other band users. This can produce "contention", a form of inadvertent competition which some protocols are designed to overcome.

Because strongly competitive band sharing is discouraged, we will use the term "co-existent" to refer to all forms of band sharing which do not involve cooperation, even though that somewhat overstretches the definition.

Table 2.2 – inspired by Peha (2009) – shows how cooperative and coexistent services interact with regulatory status to create a matrix of practical sharing arrangements.

[17] In other contexts, spectrum competition is desirable and beneficial, eg bidding for radio licences at auction, trying to win new customers with better signal coverage, etc. As for jammers, the ECC says "it is not possible to place this equipment on the market". However, "selective, sophisticated, or intelligent" jammers are permitted "for security purposes (non-civil use)" (ECC, 2004). The use of cell phone jammers has been reported in some European countries' prisons, hospitals, movie theatres, performance halls and churches.

Table 2.2. A matrix of sharing arrangements

| | **Sharing among equals** | **Sharing among unequals** |
|---|---|---|
| **Co-existent** | Licence-exempt commons<br>Unlicensed Secondaries share spectrum not used by Primary<br>Distributed trunking | Secondaries use sensing & cognitive techniques to share opportunistically with Primary<br>Inductive or UWB devices underlay licensed users |
| **Co-operative** | Mesh network<br>Channels shared among local public safety agencies<br>Centralized trunking | Secondaries "rent" spectrum from Primary<br>Secondary business users transmit freely until Primary defence agency pre-empts |

This matrix may help conceptualize ways of sharing, but it is too general to indicate which sharing arrangements are appropriate for which services, or which combinations of services are compatible. On the latter question, the UK Office of Communications (Ofcom) asked Roke Manor Research (RMR) to look at all possible pairings of nine types of radio service and identify those which are most compatible (Hulbert and Dobrosavljević, 2004). The service types were:

- cellular mobile
- terrestrial broadcasting
- satellite broadcasting
- private mobile radio (PMR)
- wireless local area networks (WLANs)
- fixed point-to-point links (P2P)
- fixed point-to-multipoint (P2MP)
- temporary point-to-point links, and
- short-range devices (SRDs)

Figure 2.3 summarizes RMR's findings in graphic form. Red means band sharing by this pair is difficult or impossible with current technology. Yellow means band sharing by this pair could work within specific limits. Green means band sharing is possible under the right conditions. The green combinations deserve a closer look if one aims to increase spectrum utilization through more band sharing.

Figure 2.3. Compatible pairings of radio service types

| System | Terrestrial Broadcast | Satellite Broadcast | PMR | WLAN | P2P | P2MP | SRDs | Temp Links |
|---|---|---|---|---|---|---|---|---|
| GSM | | Cellular uplink only | | Cellular uplink only | Cellular downlink only | | | |
| GSM/GPRS | | | | | Cellular downlink only | | | |
| UMTS | | | | | Cellular downlink only | | | |
| Terrestrial Broadcast | | | | Not home WLAN | | | | |
| Satellite Broadcast | | | | Not home WLAN | | P2MP downlink only | Not a preferred option | |
| PMR | | | | PMR uplink (digital only) | Limited planned operation | | PMR uplink (digital only) | Possible through coordination |
| WLAN | | | | | | P2MP uplink only | | |
| P2P | | | | | | | | Maybe through coordination |
| P2MP | | | | | | | | |
| SRDs | | | | | | | | No guarantee |

Source: our summary of the findings of Hulbert and Dobrosavljević (2004)

As our focus is on shared spectrum access, below we only comment on the situations involving licence-exempt applications:

**WLANs + SRDs**: This pairing is already common.

**WLANs + point-to-point:** WLAN access points could operate on frequencies which are non-interfering.

**WLANs + point-to-multipoint:** Same solution as P2P, but it is possible that a P-MP node might be attached to the outside of a building that has a WLAN inside. In that case, a directive antenna for the WLAN can prevent interference.

**PMR + WLANs**: This combination only works with digital PMR, particularly with TETRA systems. "Fine-tuning" the WLAN protocol so the transmission burst length fits the TETRA time frames would improve throughput and limit interference.

**PMR + SRDs**: Interference between TETRA systems in the 415-420 MHz band and SRDs in the 418 MHz band is already acceptable, especially in TETRA handset-to-base-station channels.

**Cellular + WLANs**: WLANs could use cellular handset-to-base-station frequencies when no nearby handset is involved in a call, operating at reduced speed when a nearby GSM handset is in a call. But if a nearby UMTS handset is in a call, the WLAN must suspend transmissions until the call is finished. The WLAN would need to be modified to recognize the difference between GSM and UMTS signals and synchronize with the former to exploit time frame "windows" in TDMA modulation.

But as noted above, generalizations are not enough to guarantee compatibility, particularly when there are *more* than two services involved. So these comments are no substitute for analysis of specific sharing situations.

### 2.5.2 The dimensions of sharing

We are used to thinking of the radio spectrum as a linear span of frequencies. But the spectrum has other dimensions as well, making it possible to share frequencies geographically, temporally, through the use of economic mechanisms, code modulation, polarization, directionality, etc.

Robert Matheson has developed an "electrospace" model of radio, in which radio is considered N-dimensional. The number of dimensions "depends on the number of characteristics of radio signals that current feasible receiver technologies can reasonably process independently from one another". (Matheson and Morris, 2011). Such processing can separate groups of radio waves received at the same time and place, enabling the suppression of interference, the recombining of scattered signals or the processing of multiple data streams simultaneously.

However, our aim is not to explore every dimension of radio. It is to highlight the diversity of options for sharing and show how the techniques used to transmit and receive radio signals create and limit those options. As new and improved techniques are likely develop as far into the future as one can see, the only limits to sharing opportunities are the cost of implementation versus the benefits derived, and the minimum service quality which must be maintained for the users.

### 2.5.3 Sharing in the frequency domain

"Command and control" rules for managing spectrum from a frequency perspective are likely to be challenged by a broader view of the possibilities:

**Channel assignments**: Traditionally, frequency use has been managed by national regulators assigning a channel – a small set of adjacent frequencies – to a specific station for exclusive use in a certain geographic area, usually through licensing.

Channelization was the first frequency sharing strategy to become formalized. For stations it represented predictable, fair and equal treatment, giving each the same usable bandwidth. The problem is that assigning a channel to a single user is like building a road where every car has its own lane and overtaking is not allowed.

Radio licences are associated with exclusive use because they not only confer the right to use a channel in a certain geographic area, they also confer a *right of non-interference* in that channel use. The non-interference right practically excludes other users of the same resources in a much larger area than the zone of authorized use. Thus, exclusivity inhibits spectrum utilization.[18]

Stable frequency assignments remain the norm in services with long-duration band plans, notably in sound and television broadcasting, where they reduce transmitter and receiver costs and help audience members find their desired stations. But static assignment is an inefficient approach for services in which channels are only used intermittently, and it leads to denial of access when there are not enough channels to meet demand. It is also problematic when two or more services with different optimum bandwidths try to co-exist.

Beyond channel assignments, band planning often leads to the creation of "guard bands", buffers around channels to prevent adjacent channel interference – for example, the 915-925 MHz "median strip" which separates handset-to-base-station channels (880-915 MHz)

[18] For example, if the coverage area of a land mobile base station in the UHF band has a radius of 21.9 km, other transmitters will be denied use of the same frequency to a distance of 69.2 km. (ITU, 2007c) In other words, the protection zone is about 9 times the size of the authorized service area.

from base-station-to-handset channels (925-960 MHz) in GSM networks. As demand for spectrum increases, regulators are re-examining guard bands established in the past to see if new applications might fit in them without interfering with existing systems, eg RFID or wireless microphones in the GSM median strip. This is because the need for guard bands of a certain size can change over time if equipment characteristics – particularly the selectivity of receivers – improve. Guard bands are a consequence of the fact that there is usually some energy spill-over from channel use: emissions do not stop exactly at the edge of a channel any more than they stop at the geographic limit of an authorized service area or at national borders.

**Interference:** Interference is the effect of unwanted energy on a radio receiver, degrading its performance or causing information loss from a wanted signal. Interference is probably the most important constraint on sharing, the one issue which must be resolved for a sharing arrangement to be acceptable. It is the reason that radio use is "rivalrous", a term economists use to indicate that one person's use of a resource limits others' use of that resource. Interference is discussed in more depth in section 2.6.

**Primary and secondary status**: In the framework defined by the international radio regulations, national governments may grant a *primary* service the right to use a particular band without being subjected to harmful interference. A *secondary* service may use the same band but with more limited rights: the secondary service must accept the risk of harmful interference from stations in the primary service while not causing harmful interference to stations in either the primary or secondary service. There can be a third usage class with even fewer rights: *permitted* use typically refers to licence-exempt, low-power "underlays" like Ultra-Wideband (UWB), which operate close to the "noise floor". Permitted uses must not cause harmful interference to others sharing the band and must accept interference from others. Short-range devices (SRDs) generally have only permitted status in licensed bands, if they are recognized at all.

When a band allocated for exclusive use by one service is re-allocated for shared use, the least loss of status is for the incumbent service to become a primary and any new user becomes either a secondary or a co-primary.

It is worth noting that government sanctioned interference protection originated as a way to improve the reliability of wireless communications, to reduce the cost of mass produced (broadcast) receivers, and to encourage private investment in radio facilities at a time when business plans were unproven and the risks of competition included deliberate interference and escalating transmitter powers (Aitken, 1994). Though well-intentioned, the effect of such sanctions was to delay the development of more robust, interference resistant equipment for many decades, and to increase private demand for radio channels. With demand for spectrum at such high levels now one may wonder how much encouragement is still needed.

**Opportunistic/cognitive-sensing-based channel access**: Assigned channels and primary/secondary status are examples of *static spectrum access rights*. Inevitably there will be gaps between the static rights conferred by regulators and the dynamically varying spectrum needs of actual communicators. To maximize spectrum utilization, the gaps between needs and rights must be reduced. If the gaps cannot be closed, they might be opened to those having unmet needs – when opportunistic sharing becomes sufficiently safe and reliable. This is the concept behind Licensed Shared Access (LSA), Authorised Shared Access (ASA), and Dynamic Spectrum Access (DSA).

Intensive but precise and dynamic spectrum sharing is the goal of "cognitive" radio. Use of the term "cognitive" is meant to suggest that the radio is aware of its surroundings, capable of figuring out what frequencies are free for its transmissions, and able to adapt

the bandwidth and power of its transmissions to create temporary links appropriate to the circumstances. Key to the incumbent services' acceptance of dynamic opportunistic sharing will be cognitive radios which never try to "borrow" an already occupied channel, and which relinquish a borrowed channel as soon as a user with higher regulatory status starts using it. Most cordless phones already have rudimentary "cognitive" capabilities, as does wireless broadband equipment for the licence-exempt bands near 5 GHz. A large number of academic researchers, corporate laboratories and projects funded by the Commission under the auspices of FP7[19] are working on problems related to cognitive radio, as it is widely appreciated how important this technology could be. If "white space devices" (WSDs) are authorized to use channels in the 470-790 MHz range not assigned to digital television stations, that will advance the commercialization of cognitive radio technology (ECC, 2011a).

However, as we discuss below, there is a wide gulf between the capabilities outlined in the previous paragraph's description of cognitive radio and what the ECC recommends for WSDs. According to the ECC, there is no need for WSDs to monitor the signal environment or make frequency availability decisions. Instead, they only need to know where they are and how to get that information to a geographic database which will set parameters for their operation at that locale. The ECC's view seems to be that the advanced capabilities envisioned for cognitive radio may be worthwhile targets, but implementations have not yet reached a stage where they are reliable enough to put into large numbers of licence-exempt products.

Nevertheless, it is clear that if and when it becomes practical, cognitive radio will dramatically alter the assumptions on which radio use and regulation are based, greatly increasing the intensity, efficiency and adaptability of spectrum use. It would solve many of the problems motivating the Commission to look at ways to enhance spectrum sharing and reduce the need for governments to micromanage private spectrum use.

**Spectrum commons (sharing without channel assignments)**: This is the approach featured in the Industrial, Scientific and Medical (ISM) bands, and the basis of the great success of Wi-Fi. *Licensed* commons are a long-standing tradition in radio and they still exist in Amateur Radio, the Maritime Mobile Service and in other bands. Even so, *licence-exempt* commons were a revolutionary development, a glimpse of a new regulatory framework which proved far more successful than anyone expected. Analogies with the internet have been suggested, and this is no coincidence: Paul Baran, who was the first to articulate "open spectrum" policies in the 1990s, was also responsible for "packet switching", the technique that makes the internet resilient and efficient without any centralization of traffic control. Baran's research suggested that the basic concepts of packet switching should work whether a network is wired or wireless, so he proposed internet-like rules for the regulation of radio.[20]

The rules of a licence-exempt spectrum commons are simple:

- No assigned channels and no exclusivity in channel use
- All users have equal rights

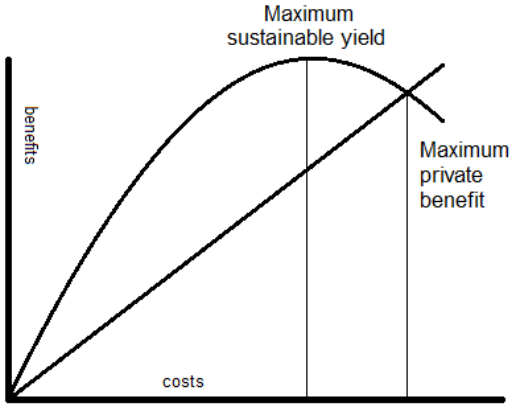
[19] European Commission: ICT Research in FP7, http://cordis.europa.eu/fp7/ict/

[20] The first public presentation of Baran's argument for "open spectrum" was in his keynote speech at the Marconi Centennial in Bologna, Italy, in June 1995. In addition to arguing for *minimalism* in radio regulation, the speech proposed moving television broadcasting to cable so the UHF band could be opened for new uses under technology- and service-neutral rules. http://wireless.oldcolo.com/course/ baran2.txt

- Only equipment fulfilling certain technical requirements can be used. The technical requirements restrict signal strength and bandwidth, so the harm one user can inflict on another is limited.
- No one should deliberately cause interference, but if interference occurs, each user must deal with it as best they can.

Much has been written about the "tragedy of the commons", the supposedly inevitable overuse of an unpriced but finite shared resource. It is a cautionary tale which seems all too logical. Could it represent the fate of the overly popular 2.4 GHz band? We will take up this question later, but in the meantime, one should not forget that there are many examples of commons which remain in stable use for generations.

Figure 2.4. Private use of a shared resource.




Source: Ostrom (2009)

Economist Elinor Ostrom has an explanation for that, summed up in Figure 2.4.[21] Each individual user of a commons assumes there is a simple, one-to-one relationship between their use of shared resources and their private benefit: "the more I use, the more I benefit". But from the commons' perspective, the relationship is not linear: as use of shared resources increases, marginal gain decreases, collective benefit tapers off as a maximum sustainable yield is reached, and then further use diminishes collective benefit. The place where the lines representing individual and collective benefit intersect represents equilibrium. It indicates that the system will tend to evolve past the point of maximum sustainable yield, because individuals value their own benefits more than the collective's. But the overuse of common resources should not continue past the point where the two lines cross, if the individual users are rational, because at that point they see future benefits failing to meet their expectations, so they stop trying to use more of the resource.

This is an oversimplification, of course. The lines are symbolic and the intersection can be close to or far from the point of maximum yield, depending on how much individual and collective benefits differ. Yet this diagram shows how private use of a shared resource can be neither optimal nor tragic but rational and sustainable.

[21] Diagram from Ostrom, E., Going beyond the Tragedy of the Commons, Stockholm Resilience, 2009, http://www.stockholmresilience.org/1105.html

As the definition of "collective use of spectrum" suggests, it is possible to limit a commons to one or a few specific applications, or to leave it open for any sort of application. The latter may be a purer implementation but practical considerations might justify a safer model. Here are a few variations:

- *Private spectrum commons* – Some people see mobile telecommunication networks as working like a private commons. However, the US Federal Communications Commission relates private commons more to spectrum subleasing than to services providing access to infrastructure. By limiting application of the private commons model in the USA to "advanced" peer-to-peer devices and closed user groups, and forbidding negotiations for service contracts, the FCC seems to be positioning private commons as a vehicle for technical innovation and experiment rather than as an ordinary business activity:

  > A 'private commons' arrangement is… permitted in the same services for which spectrum leasing arrangements are allowed… [A] licensee or spectrum lessee makes certain spectrum usage rights under a particular license authorization available to a class of third-party users employing advanced communications technologies that involve peer-to-peer (device-to-device) communications and that do not involve use of the licensee's or spectrum lessee's end-to-end physical network infrastructure (e.g., base stations, mobile stations, or other related elements… [A] private commons arrangement does not involve individually negotiated spectrum access rights with entities that seek to provide network-based services to end-users. A private commons arrangement does not affect unlicensed operations…
  >
  > Prior to permitting users to commence operations within a private commons, the licensee or spectrum lessee must notify the Commission… This notification must include information that describes: the location(s) or coverage area(s) of the private commons under the license authorization; the term of the arrangement…[22]

- *Managed spectrum park* – this is what New Zealand calls their "light licensed" 2575-2620 MHz band, which is intended for regional and local network services. Licences are awarded on a "first-come, first-served" basis. Sixteen entities have applied so far. After a sign-up fee, licensees pay an annual fee for spectrum "rent" and to cover the cost of services provided by a private band manager. The manager can change the park rules if all licensees are given prior notice, and two-third of the licensees can change the rules if the manager approves their vote. Licensees "must fully employ interference mitigation techniques… to maximize co-existence with systems of other Licensees". New applicants for the park's frequencies may send "interference risk notices" to licensees if they foresee a risk of mutual interference. The band manager can require licensees to coordinate their frequency use and negotiate agreements, subject to mediation or arbitration.[23]

  The extra layer of rules, protocols and formal obligations provides enough ways to manage interference that stations in the "spectrum park" operate at higher powers than are allowed in licence-exempt commons.

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[22] US Code of Federal Regulations (2010), Private Commons, 47 CFR 1.9080, http://www.gpo.gov/fdsys/pkg/CFR-2010-title47-vol1/pdf/CFR-2010-title47-vol1-sec1-9080.pdf

[23] Managed spectrum park: Park rules, New Zealand Ministry of Economic Development - http://www.rsm.govt.nz/cms/pdf-library/policy-and-planning/radio-spectrum/managed-spectrum-parks/managed-spectrum-park-park-rules

### 2.5.4 Sharing in the spatial/geographic domain

Geographic re-use of frequencies is the most important factor in maximizing the value of the radio spectrum. Not only is it essential to the spectrum efficiency of cellular networks, but it is largely responsible for a million-fold expansion of the information-carrying capacity of the spectrum as a whole since 1948. As the US Commerce Department's Spectrum Management Advisory Committee explained:

> Of that million-times improvement… roughly 15 times was the result of being able to use more spectrum… About 5 times was from using frequency division, that is, the ability to divide the radio spectrum into narrower slices…, and about 10 times [was] through the use of improved modulation techniques. Most of the million times improvement since 1948 was the result of geographic sharing [limiting signal range so the same frequencies can be used simultaneously in different locations]… Geographic sharing, in the form of MAS (multi-antenna signal processing – also known as "smart antenna," MIMO,24 adaptive arrays, etc.), has the potential to extend improvements well into the future…"25

Four aspects of spatial/geographic sharing stand out as important to this study:

**Licensed use of spectrum and protection zones**: radio licences authorize the use of a span of frequencies *within a specific geographic area*. Normally a protection zone is also specified, because radio licences bundle rights of use with rights of non-interference. A protection zone is an area in which other systems are forbidden to emit energy into the licensee's authorized spectrum mask at a level sufficient to cause harmful interference. A flexible version of a protection zone is a "mitigation" zone, where potentially interfering emissions are permitted, but if harmful interference occurs, the interferer must coordinate their spectrum use to eliminate the interference.

**Exclusion zones** are used to ensure adequate separation distance between stations in the same or in different services which could produce harmful interference if they were closer. If the stations excluded from a zone are licensed, the regulatory authority can ensure that the zone is not violated simply by not authorizing stations within the zone. If the excluded stations are licence-exempt, other means must be found to prevent operation in an inappropriate location: for example, location awareness, geo-database control, signal sensing or warning beacons.

**Directional and geographic service-related separation**: Directional band sharing, for example, between the terrestrial fixed services and various satellite services, is common, because while the terrestrial fixed stations have their antennas aimed horizontally, satellite dishes face skywards to receive and transmit with narrow beams, at precise angles. It is also common for the maritime and land mobile services to share an allocation – not to inter-communicate, but because their zones of operation are non-overlapping (except for islands and coastal areas).

Another variation on geographic sharing is likely to become increasingly important in the years ahead: beam-forming. Many portable wireless devices have omnidirectional radiation patterns: they emit and detect radio energy in all directions, even if they only need to communicate with one station at a particular location. But higher radio frequencies, which

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[24] MIMO = Multiple Input, Multiple Output – this is a relatively new technique for spreading a radio communication over a small group of antennas to increase throughput by using "beam-forming" to create complementary data streams to be recombined in the receiver. MIMO can significantly increase data transfer rates without requiring additional bandwidth or transmit power.

[25] Spectrum Management Advisory Committee, (Working Group 1 (2008), *Definitions of Efficiency in Spectrum Use*, National Telecommunications and Information Administration, US Department of Commerce, p 7, http://www.ntia.doc.gov/files/ntia/publications/spectral_efficiency_final.pdf

are coming into wider use now, can be focused and aimed with reasonable precision by relatively small antennas, and techniques for doing this electronically, without physically moving the antennas, are now well understood. That applies to reception as well as transmission. Just as we can focus our eyes and ears on a particular source and ignore other stimuli, "smart antennas" can focus their "attention" on particular targets, too, which will make it possible to improve link quality while using (and wasting) less energy, and for separate systems to operate in closer proximity without mutual interference. Recent work by the FP7 SAPHYRE project has shown that adaptive sharing among separate networks using beam-forming techniques can support much more intensive spectrum utilization than the static partitioning of frequencies and operating areas. But to achieve "these gains the operators need to cooperatively design their beamforming vectors striking a balance between the conflicting goals of maximizing the signal power and minimizing the generated interference. This cooperation does not need to rely on regulation, but in principle it is self-enforced since it is beneficial to all involved parties". (Karipidis, 2011)

**Location awareness –** Satellite-referenced and ground-based positioning systems now enable portable devices to determine their location coordinates. This supports personal navigation, geographic data collection, localized messaging, asset tracking, telework management, etc. Similarly, the development of an internet accessible, geolocation database control system for "white space devices" in the UHF band could provide regulators with a versatile new infrastructure, enabling them to manage the frequency use and power output levels of licence-exempt devices throughout their territory, and in bands beyond UHF. This possibility is discussed in Chapter 3.

### 2.5.5 Sharing in the temporal domain

Time division multiplexing is a technique which interleaves signals temporally, combining 2 or more data streams into one bandwidth. This was developed to enable one phone line to carry simultaneous conversations and it was successfully transferred to the wireless domain as a by-product of digitalization.

However, on a larger time scale, opportunistic time sharing is enabled by cognitive radio, which can detect gaps in channel occupancy and "borrow" a channel for the duration of the gap. The cognitive element helps discover where and when there are exploitable openings. Of course, what constitutes an "exploitable opening" depends on the requirements of the borrowing system: if only a few milliseconds are needed, many more opportunities will be discoverable than if the requirement is for hours of access.

### 2.5.6 Trunking

The core idea of a "trunked" radio system is to replace separate systems requiring dedicated radio channels with a shared infrastructure based on pooled frequencies. A trunking "controller" separates logical channels from physical channels so the available radio frequencies can be employed as needed to support the specific one-to-one, one-to-many, and many-to-many call sessions underway at any moment. The efficiency gains of trunking are substantial, and increase with the number of channels available. For example, reasonable assumptions about call durations and blocking rates would lead one to expect 10 trunked radio channels to support 39 different users, 20 trunked channels to support 110 users, or 100 channels to support 809 users.[26]

[26] These gain estimates are based on formulas devised by the Danish mathematician A. K. Erlang. Our examples assume requests for one-to-one call sessions arrive at random intervals, each call averages 6 minutes in duration, and the probability of no channels being available when a call request is received is less than 0.005. However, call requests and durations are *not* random in the real world. Clustering is

Some aspects of trunked systems are similar to cellular – the pooling and temporary assignment of radio channels, for example. A trunked system can consist of a single base-station with wide area coverage (frequency bands for services using trunking tend to be lower than the frequency bands for cellular so the range is greater), or a matrix of base-stations for even wider-area coverage. As the primary market for trunked radio systems so far has been governmental (public safety and law enforcement), and private organizations that would otherwise need their own Professional Mobile Radio (PMR) system, additional capabilities have been layered onto the basic trunking concept to support the communication needs of teams working in risk situations: all-calls (broadcasts), "any-to-any" communication, direct "walkie-talkie" mode, handset relays for other handsets, talk groups whose membership can vary, alert messages, etc. Because the efficiency gain is greater when more channels are pooled and coverage is expanded, trunked systems are often nationwide in scope, shared by multiple agencies which frequently cooperate (a common combination is police, fire and emergency medical).

Trunked systems tend to be expensive, though the costs of individual components are highly variable. The software needed to support migration from older systems and coordinate sophisticated communications arrangements on the new system must often be customized for a specific organization. However, most system costs are due to the complex yet rugged handsets.

Developed by ETSI, TETRA (TErrestrial Trunked RAdio, EN 300 392-2) is probably the best known trunking system in Europe. But there are others: of particular interest is Digital Mobile Radio (DMR), another open ETSI standard (TS 102-361), whose channels fit the 12.5 kHz bandwidth of Professional Mobile Radio's analogue channels while doubling the information-carrying capacity with TDMA. DMR systems are 3-5 times cheaper than TETRA (mainly because DMR base stations offer coverage areas 2-3 times larger than TETRA's so fewer base stations are needed). DMR's dual mode analogue/digital equipment with "drop-in" 12.5 kHz channel width makes transitions from dedicated analogue to trunked digital easy.[27] Not many professional user groups need – or can afford – a system like TETRA, but DMR could have more take-up if incentives for infrastructure sharing were adopted.

### 2.5.7 Sharing in vector domains

When radio waves are aligned in a uniform orientation, this is called "polarization". Antennas can be oriented, too, in which case the antenna's orientation will hinder or help transfers of energy to or from the surrounding electromagnetic field according to the orientation of the radio waves in that field. That enables antennas to discriminate signals by their polarization. Satellites, for example, use orthogonal polarizations in their downlinks: a satellite receiver can detect a vertically polarized signal without detecting a horizontally polarized signal transmitted on the same frequency from the same satellite at the same time. That makes frequency re-use possible for the satellite, while enabling the reception of two different programs at the earth station just by turning the LNBF.[28]

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observed when communication activity is triggered by events and linked to the behaviour of teams, so effective capacity may differ from Erlang predictions. Empirical studies and more sophisticated models are needed to identify the actual spectrum requirements of different user groups using trunked systems. (Can, 2003)

[27] TETRA is optimized for high-traffic/dense deployments while DMR is optimized for expansive coverage.

[28] Low-Noise Block Down-converter and Feedhorn – the device which captures the satellite signals at the focal point of the dish and feeds them to the amplifier.

Frequency reuse through polarization is also common in terrestrial fixed (point-to-point) microwave links which, in addition, rely on antenna directivity and azimuth (angle of arrival) to limit interference between systems using the same frequencies in the same landscape. . At higher frequencies, radio behaves like light, propagating along straight paths and readily focusing into narrow beams. Beamforming and beamsteering are expected to become increasingly important as ways to boost the efficiency of spectrum use.

### 2.5.8 Sharing in the code domain

Frequency-hopping spread spectrum signals in the 2.4 GHz band are common examples of pseudo-random codes enabling different signals to use the same span of frequencies at the same time with little interaction. Variations on the theme of code modulated spread spectrum enable spectrum sharing with low interference risk. In general they substitute computer processing power for bandwidth.

CDMA (Code Division Multiple Access) mobile cellular systems implement this approach. A wideband variant (W-CDMA) is used in 3G networks. The newer OFDM (Orthogonal frequency division multiplexing) is used in WLANs, WiMAX and the 4G cellular radio interface because of its high spectral efficiency and noise immunity. Coded Orthogonal Frequency Division Multiplexing (COFDM) is yet another variation, especially well suited to broadcasting as it copes well with the multi-path propagation common in cities. COFDM has been incorporated into both Digital Audio Broadcasting (DAB) and Terrestrial Digital Video Broadcasting (DVB-T), and it led to the concept of a single frequency network (SFN) in which an array of synchronized transmitters broadcast the same signal on the same channel, eliminating the need for multiple channels to cover a large area. (Stott, 1998) SFNs could deliver a second "digital dividend" because the efficiency gain from SFNs is even greater than from analogue-to-digital switchover. Traditional network planning principles limit re-use of a channel to 11% of the surrounding area (Fernández, 2000).

### 2.5.9 Sharing in the economic domain

Market forces can determine resource allocations and address problems related to the exercise or violation of rights. There are several different mechanisms:

**Auctions:** When the Commission embraced competition in telecommunications and a larger role for market forces in radio spectrum management, distributing new licences by auction followed logically. This is particularly recommended when demand for a particular set of channels exceeds supply. Ronald Coase is often cited as the first promoter of spectrum auctions and "propertizing" the radio spectrum. But Coase is also cited by supporters of licence-free commons:

> "As [Coase] famously wrote in a 1959 *Journal of Law and Economics* article about the Federal Communications Commission, 'All property rights interfere with the ability of people to use resources. What has to be insured is that the gain from interference more than offsets the harm it produces.' Thus, before deciding *in whom* property rights for some resource should vest, a proper Coasean should determine *whether* the resource should be the subject of property at all. That decision should be based upon whether propertizing the resource would produce a gain that 'offsets the harm it produces'…" (Lessig, 2004).

So Coase's first question can be rephrased as: does the free use of a band of radio frequencies contribute more to society than propertizing that band? Those who have considered this question generally reply that it depends on what the access is for: the economic value of certain licence-exempt applications (RFID, for example, or public Wi-Fi "hot spots") is said to be greater per MHz than any licensed application, but other

licence-exempt applications are worth much less.[29] By the same token, some licensed services contribute more to the economy than others. The same can also be said of government services. However, the existence of a few high value government services or licence-exempt applications or licensed services does not mean that giving the entire radio spectrum to any one category would maximize wealth. That begs the question of *how much* spectrum should be allocated for free access, for government use or licensed for sale to the highest bidder. Auctions have been proposed as a way to decide that, although that remains an offbeat and largely untested strategy.[30] However, if auctions with reserve prices were used to award geographic exclusivity and rights of non-interference rather than spectrum use rights, they could be a way to apportion shared and unshared access.

Because spectrum rights offered at auction always have an element of exclusivity, to enhance their value as property, auctions are not a suitable mechanism for awarding access to non-exclusive modes like spread-spectrum or ultra-wideband. Even "light licensing" is problematic at auction. More attention needs to be paid to the impact on licence auctions of the many new authorization classes emerging *between* licensed and licence exempt.

**Licence trading** – Denmark was the first country in Europe to authorize spectrum licence trading, as early as 1997.[31] Many more followed as a consensus emerged that aftermarkets boost the economic efficiency and benefits of using market mechanisms in the distribution of licences (Analysys, 2004). "Without fluid secondary markets, there is no reason to believe that any given current allocation of spectrum rights indeed reflects presently-efficient allocation" (Benkler, 2011). According to ECC Report 169, only 4 of 22 survey responses from CEPT administrations indicate that radio licence trading is not permitted in their country. Two of the 4 (Estonia and Ireland) are preparing rules for trading, and a third, Cyprus, has a law allowing trading although implementing regulations have not been approved yet. Thus, among the respondents, only Russia is definitively against the trading of radio licences.

For EU member states, the Framework Directive (2002, amended 2009) allows the leasing and subletting of spectrum usage rights. But at least 11 countries - Croatia, Czech Republic, Estonia, Ireland, Lithuania, Malta, Romania, Russia, Slovenia, Sweden and Switzerland - indicated in a CEPT survey that they do not permit spectrum leasing. However, Estonia, Malta and Sweden intend to change their policies soon. National restrictions on spectrum leasing could impede the implementation of Authorised Shared

[29] A study by Indepen, Aegis and Ovum (2006) estimated the value to the UK's economy of two Wi-Fi applications in the year 2026: £78bn/year for public access hotspots and £856 million/year for wireless home networks. However, their assumptions were excessively conservative: ie, that there could only be 8.7 outdoor and 19.5 indoor Wi-Fi access points per $km^2$. Moreover, the study was produced before the release of the iPhone and the first tablets. A recalculation of the maximum values today would have to be many times larger. Nevertheless, the consultants conclude that "the major LE [licence-exempt] applications will probably generate net economic benefits per MHz which substantially exceed those generated by the most valuable licensed applications, mobile telephony and broadcast…" (Indepen, 2006).

[30] The US Republican Party introduced legislation in July 2011 which would stop the US Government from releasing any more spectrum for licence-exempt use unless that spectrum is first offered at auction for both licensed and unlicensed use and "the bids for unlicensed use, in the aggregate, exceed the highest bid for such license". House Republicans, Spectrum Innovation Act of 2011, http://republicans.energy commerce.house.gov/Media/file/Hearings/Telecom/071511/DiscussionDraft.pdf. A more sophisticated version of this idea is described in Carter, K. (2006) Next Generation Spectrum Regulation for Europe: Price-Guided Radio Policy, WIK Discussion Paper No. 326, http://ssrn.com/abstract=1522038

[31] Data in this "Spectrum trading" subsection comes from ECC Report 169 (2011): Description of Practices Relative to Trading of Spectrum Rights of Use, http://www.erodocdb.dk/docs/doc98/official/pdf/ECCRep169.pdf

Access (ASA) and Licensed Shared Access (LSA) as these may constitute temporary spectrum leasing arrangements.

**Private frequency managers** – The interest among policy makers in using market mechanisms and economic forces to make spectrum management more efficient extends to the outsourcing of responsibility for managing specific bands. We already encountered this in New Zealand's "managed spectrum parks" and the US' "private commons". Across the globe, other non-governmental frequency managers can be observed:

> *Band manager for a specific industry:* Since 1997, the UK has outsourced licensing and spectrum management services for Programme Making and Special Events (PMSE) to a private company, the Joint Frequency Management Group (JFMG Limited). JFMG have the exclusive right to license and coordinate permanent and temporary use of frequencies by wireless cameras and microphones in studios, theatres, schools, concert halls, churches and at outside locations. In support of these functions, they operate a website with self-registration forms and information about the current availability of frequencies, licence fees, discussions about possible future changes in allocation, etc. They also represent the interests of PMSE professionals in regulatory consultations.
>
> *Geo-database managers for white-space devices* – the US Federal Communications Commission has selected 9 companies to manage the geographic databases which will control the frequency use and power output of licence-exempt devices authorized to use unassigned DTT channels (FCC, 2010). Spectrum Bridge is the first of the 9 approved to begin serving the public, on 26 January 2012.[32] Each WSD must report its location regularly to one of the databases via internet in order to receive operating parameters and authorization to transmit. Even though they will compete with one another for clients, the database administrators must also cooperate so their data is consistent and organized in a common format, with agreed procedures for end-users to migrate easily from one geo-database service to another.[33] In future the services offered by each administrator may differentiate – particularly in the user interface, mapping software and help services. Eventually they may use different algorithms to calculate propagation and derive operating parameters for the WSDs. But the business model supporting the geo-database services is not yet clear.
>
> The same can be said of Europe, where ETSI has developed a report on cognitive radio in UHF white spaces, use cases and methods for protecting primary/incumbent users and standards for spectrum sharing and coexistence between cognitive Radio Networks.[34] CEPT project team SE43 is also developing guidance documents for national regulators. An ECC report on WSDs released at the start of 2011 gave detailed but generic descriptions of geo-database operation.[35] The UK is now furthest along in translating those ideas into

[32] FCC Chairman Genachowski Announces Approval of First Television White Spaces Database and Device, press release, 22 December 2011, http://transition.fcc.gov/Daily_Releases/Daily_Business/2011/db1222/DOC-311652A1.pdf

[33] "Database managers must agree that they will not engage in any discriminatory or anticompetitive practices or any practices that may compromise the privacy of users." (USA, 2011)

[34] TS 102 908

[35] ECC Report 159, Technical and Operational Requirements for the Possible Operation of Cognitive Radio Systems in the 'White Spaces' of the Frequency Band 470-790 MHz (Cardiff, January 2011), http://www.erodocdb.dk/docs/doc98/official/pdf/ECCREP159.PDF

regulations (Ofcom, 2011), but harmonized regional policies will not be agreed until 2012. These processes are explored in more detail below.

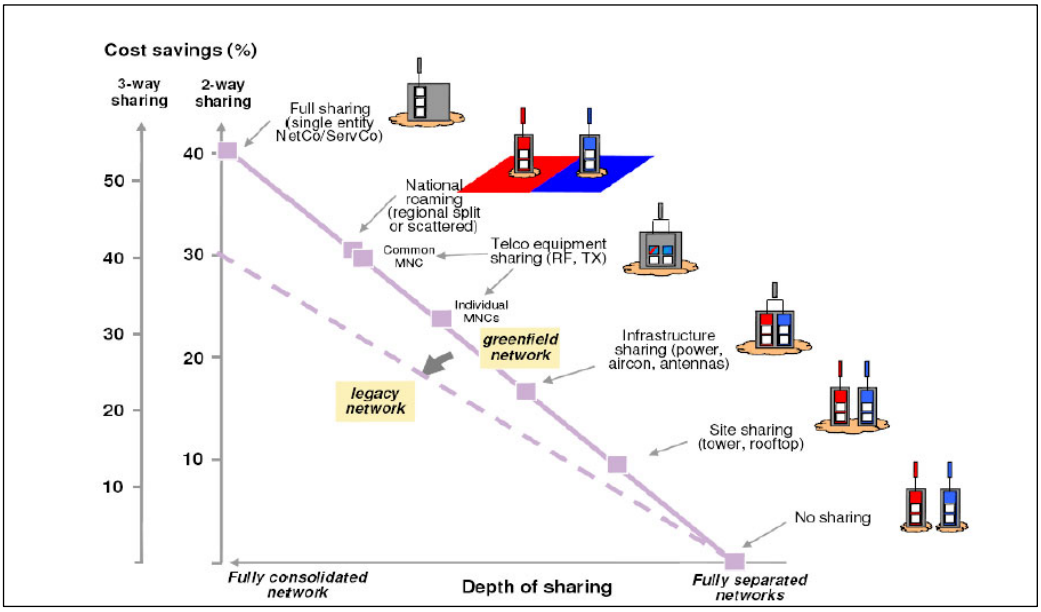
*Facilities-based managers* – the radio environment is complex in large facilities like airports, shopping centres and office buildings, with multiple Wi-Fi networks, femtocells, wireless controls for temperature, windows and air circulation, motion detectors and wireless alarms, video, voice and data networks for security, etc. Spectrum management for large facilities is a professional specialization, supplementing rather than substituting for governmental regulators. But the argument has already been made that legal responsibility for regulating the spectrum within large facilities could or even should devolve to property owners (Snyder, 2007).

**Infrastructure sharing and competition policy** – Wireless network operators have shown growing interesting in infrastructure sharing in recent years, and there is growing acceptance of the idea among regulators, even though it could undermine competition. As our discussion of trunking indicates, major gains in efficiency of spectrum use can come from infrastructure sharing. There may also be significant cost savings (see Figure 2.5), which could be passed on to consumers (Norman, 2010). The issue is becoming especially important in cellular mobile, where the large bandwidths needed for efficient use of 4G channels, the technical constraints of base station hardware and a likely insufficiency of allocated spectrum combine to make it difficult to accommodate as many geographically complete 4G networks as there are licensed carriers. The European Common Proposals for WRC-07 supporting a "single network solution" for IMT-Advanced[36] signalled at least provisional acceptance of cellular infrastructure sharing. However, the integration of network services envisioned for IMT-Advanced, combining what are now separate markets, poses a challenge for competition policy. Much depends on how IMT-Advanced is organized as a business.

Infrastructure sharing reduces the dimensions in which carriers compete. In the early days of cellular, operators competed mainly in coverage. But when competitors share base stations, backhaul links, etc., competition is reduced to differences in secondary matters.

[36] Addendum 4 to European Common Proposals for the Work of the Conference, WRC-07 Document 10-E (July 2007) - http://www2.fcc.gov/wrc-07/rcp/cept/add10-4.doc IMT-Advanced is the name used by the ITU to describe a "network of networks" incorporating broadband, broadcasting, peer-to-peer, hot-spots, satellites, etc., into the network management, business processes and billing systems at the core of today's cellular mobile networks.

Figure 2.5. Potential savings from network sharing




Source: Vodafone (reprinted in BEREC-RSPG, 2011).

Some argue that infrastructure sharing facilitates the entry of new market players, as they do not have to create a new network from scratch. But sharing arrangements can also be used to exclude newcomers, unless regulators mandate and enforce openness and non-discrimination. As a recent BEREC-RSPG joint report on infrastructure sharing in mobile/wireless networks noted:

> …infrastructure sharing agreements may raise the issue of their compatibility with Article 101 of the Treaty on the Functioning of the European Union (TFEU). Particularly, concerns can appear that relate to the immediate effects on competition in upstream and downstream markets, but also to the possibilities of the involved operators to collude or to exchange confidential information. Eventually, the assessment depends on the own facts and merits of each case (BEREC/RSPG, 2011).

## 2.6. Constraints on sharing

### 2.6.1 Interference

As noted above, interference is the most important constraint on frequency use and on band sharing, yet quantitative measures of interference have gained only limited acceptance after a century of radio use. This is due to the fact that different signals affect different devices supporting different applications in different environments in different ways. In 2005, the US National Telecommunications and Information Administration collected "established" interference protection criteria from around the world. Their collection fills 140 pages (Paul, 2005).

For a while it looked like "interference temperature", based on the radio astronomy concept of "noise temperature", might finally provide an objective and uniform metric. But it was abandoned when the perception grew that it might undermine existing interference protections and victim rights (Kolodzy, 2006).

A standard vocabulary has developed over decades to describe degrees of interference qualitatively, including *accepted*, *permissible* and *harmful*. The Authorization Directive's definition of harmful interference is:

> …interference which endangers the functioning of a radionavigation service or of other safety services or which otherwise seriously degrades, obstructs or repeatedly interrupts a radiocommunications service operating in accordance with the applicable Community or national regulations. [37]

In that definition it does not matter if a particular signal is "wanted" or "unwanted". But in less harmful situations it does. Consider multipath propagation: this is caused by objects in the environment bending radio waves so they reach a receiver by different paths and with different time delays. In analogue television, multipath causes "ghosting", a relatively mild form of picture interference. In digital television, the time delay can be corrected, with the result that multipath adds to the received signal strength. Thus it is no longer considered interference. In other words, "unwanted" emissions can become "wanted" if someone figures out how to exploit them. Using interference to improve channel quality may be paradoxical, but it is a new area of active research, with great potential for expanding opportunities for channel-sharing, particularly in bands where users must resolve their own interference problems.[38]

The traditional approach to interference management assumes that interference is caused by unwanted transmissions entering a victim receiver. Therefore, to prevent interference, strict limits are imposed on transmitters in terms of maximum permitted power output, minimum separation distance from potential victims, listen-before-transmit obligations, etc., while the capabilities of receivers are left unregulated.

A completely different understanding of interference is expressed by Matheson:

> The victim receiver is always culpable in cases of interference, since a sufficiently capable receiver (possibly outrageously complex and expensive) could always be constructed to operate adequately in the presence of any unwanted signal that was radiated from a different antenna than the desired signal. Any instance of interference is *prima facie* evidence that the owner of the receiver didn't provide a good enough receiver. There is no technical basis to say that some interference is caused by inadequate receivers, while other interference is not. Regulations that protect against interference operate by allowing interference-free service using simpler or less expensive receivers (Matheson, 2003).

From this perspective, interference is always due to receiver inadequacy, and the purpose of traditional interference management is to enable the sale of inadequate receivers. This may sound cynical, even inflammatory, but it recalls a time when the production of radio equipment was dominated by broadcasting and receivers outsold transmitters by many thousands to one. The regulatory treatment of interference developed in that era. Matheson is simply stating a truth long known to engineers: if radio receivers were more selective and robust – and they could be – constraints on transmissions could be relaxed and more transmitters allowed to operate.[39] But he is also ignoring a truth long known to environmentalists: preventing pollution is easier than cleaning up afterwards.

It is undeniable that receiver performance imposes constraints on transmitters. The FCC's Technological Advisory Council notes that the poor selectivity of analogue TV receivers "was a major factor in the creation of white spaces" (TAC, 2011). And now it is clear that the selectivity of DTT receivers is limiting the spectrum which could be used by WSDs. A

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[37] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:108:0021:0021:EN:PDF "Accepted" and "permissible" interference are terms used in an ITU context when one country's frequency use must be coordinated with another country's because of a risk of crossborder interference.

[38] See, for example: Lee (2011); Gollakota, (2011); and Talebi.

[39] Selectivity is a measure of a radio receiver's ability to tune in one channel while rejecting energy from adjacent channels.

survey of DTT white space near Munich, Germany, conducted by the FP7-funded research project COGEU found 16 empty channels (128 MHz). But if the channels adjacent to occupied channels must also be avoided in order to protect DTT reception, as is likely because of the poor selectivity of most DTT receivers, then only 8 channels (64 MHz) would be available for WSDs (COGEU, 2010b). The researchers point out that:

> Manufacturers currently have little incentive to maximize the interference tolerance of DTT receivers and there is still a lack of standard for minimum interference rejection for DTT receivers. Furthermore, there may be legitimate concerns that the current system provides incentives to those who may suffer from interference to complain to the regulator and block the launch of the new service rather than take actions and invest in more efficient receivers. This may occur even when the cost of replacing receivers is significantly less than the benefits from the new service (COGEU, 2010a).

We will revisit these issues in the next chapter, when discussing minimum standards for receivers and the opening of UHF white spaces.

### 2.6.2 Congestion in licence-exempt spectrum

A further constraint is congestion of spectrum when shared by many users – the key issue raised in discussions of licence-exempt commons. Perhaps the best litmus test is to examine the most widespread wireless broadband technology, Wi-Fi.

There is remarkably little agreement among experts on how many Wi-Fi nodes can co-exist in one square kilometre before congestion becomes a problem. Early estimates of the capacity of the 2.4 GHz band varied from one outdoor Wi-Fi node per square km to a maximum of about 75.[40]

And yet, MASS Consultants, which was commissioned by Ofcom UK to conduct the most intensive Wi-Fi congestion detection campaign anywhere in the world, measured a Wi-Fi node density of 2247 per km$^2$ in the area around Kings Cross station in London in 2008-9.[41] The areas around London's railway stations had measured node densities 50% higher than any other locations in MASS' survey, including the rest of London, where the Wi-Fi density in monitored areas averaged about 1200 nodes per km$^2$. The researchers also sampled six other towns and cities where they found node densities in the 100-300 per km$^2$ range.

Part of the problem of recognizing congestion and estimating how dense Wi-Fi deployments can be without performance degradation is that Wi-Fi normally generates a lot of lost or damaged packets, resulting in resends and retrains. And yet the user rarely notices this, because Wi-Fi's performance margin for activities like web browsing and email reading is so high. Unfortunately, damaged packets and resends are also symptoms of channel congestion. Thus the difference between congested and normal Wi-Fi operation is not clear cut. According to Rodrig (2005), up to 60% of Wi-Fi's airtime is consumed by resends and overheads – suggesting, as others have noted, that politeness protocols are a significant source of inefficiency in radio channel use. More to the point, in Wi-Fi the onset of congestion is gradual and not easily detected.

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[40] Aegis (Leeson, 2000) predicted that fixed point-to-point networks using the 2.4 GHz band in England, along with portable electronic newsgathering equipment, would make it impossible for even one outdoor Wi-Fi node per kilometre to operate without interference, but up to 40 indoor nodes might co-exist within one square kilometer; Hansell (2004).

[41] MASS actually reported the peak node density as 749 per channel per km$^2$. But since there are 3 non-overlapping IEEE 802.11b channels in the 2.4 GHz band, we asked the leader of the MASS survey, Adrian Wagstaff, if it would be accurate to say that the total node density in any locale was 3 times the per-channel node density. He agreed, so in this synopsis we have multiplied all of MASS' per-channel measurements by 3 to get band totals.

In general MASS found Wi-Fi into Wi-Fi interference (ie genuine congestion) less of a problem than interference into Wi-Fi from baby monitors, video senders, cordless phones and microwave ovens. Moreover, the density of nearby Wi-Fi nodes proved an unreliable predictor of performance degradation. What mattered more was how much traffic was passing through the nodes.

The main conclusions reached by MASS were that:

- "The majority of problems experienced by Wi-Fi users are not spectrum-related. Users are likely to attribute their problems to congestion, but most of the time the problems are due to wired Internet problems or device configuration errors.
- "Interference is commonplace and is a more important cause of wireless networking problems than congestion… there are a lot of radio types in use and the interference problem is predicted to continue to increase.
- "Inner city locations are extremely busy and do exhibit signs of congestion as well as interference. We expect this to be occurring in most large cities of the UK" (Wagstaff, 2009).

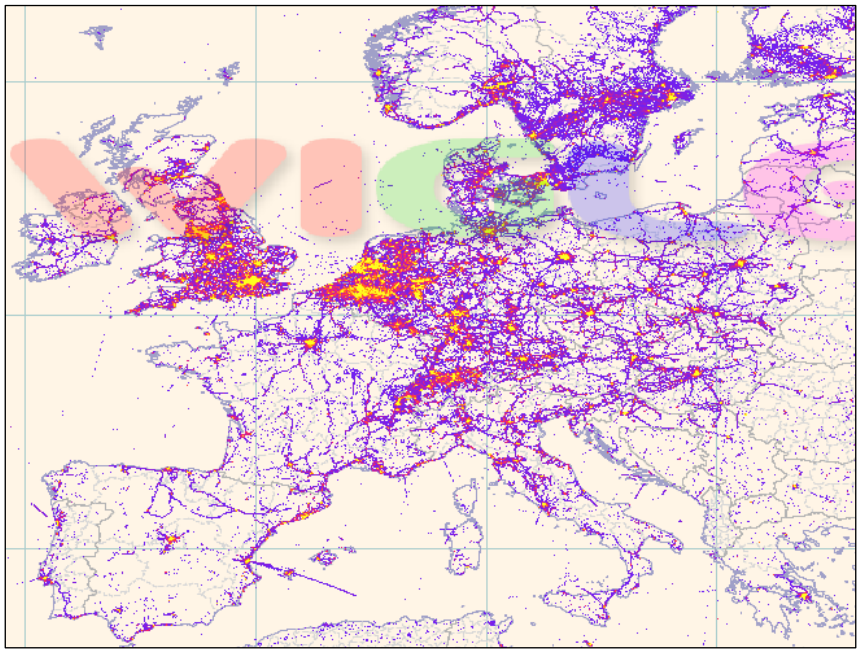
Some points may require explanation. First, the distinction between "interference" and "congestion": "congestion" is the result of Wi-Fi/Wi-Fi interference, while "interference" is caused by non-Wi-Fi emissions adversely affecting Wi-Fi. Second, MASS's conclusion that interference into Wi-Fi is a more serious problem than congestion does not lead them to suggest reserving 2.4 GHz exclusively for Wi-Fi. Rather, they propose a testing programme for non-Wi-Fi devices to be certified as "Wi-Fi friendly" if they are designed for reduced interference into Wi-Fi. Presumably buyers would take note of that certification – or its absence – and make purchase decisions accordingly.

In terms of what other regulators can learn from this exercise, MASS argues that the only way to gain reliable information about the status of congestion in bands for short-range devices (SRDs) is to walk around, indoors and out, with a handheld monitoring device. For their survey, they used a common type of internet tablet with Wi-Fi and GPS modules built in. Monitoring and logging software was stored in the tablet's memory.

The Wireless Geographic Logging Engine (WIGLE.NET) is building a database of Wi-Fi node locations and has already registered nearly 52 million unique identifiers – about 15% of the global total. Their maps indicate that the Wi-Fi density of central Europe is similar to the UK's and the Benelux countries have node densities comparable to London's but covering a much bigger area (see Figure 2.6). When the WIGLE map is superimposed on a population density map of Europe, it is clear that Wi-Fi density already correlates to a high degree with population density. That indicates Wi-Fi ownership is well on its way to becoming universal. Eventually, population density may, by itself, suggest the local probability of Wi-Fi congestion.[42]

[42] Sandvig (2007) proposed the use of census and demographic mapping data to predict Wi-Fi congestion, but his results were inconclusive. As Wi-Fi ownership approaches 100% of households, this method might become viable.

Figure 2.6. Wi-Fi node density in Europe (August 2011)



Source: WIGLE.NET

A report recently commissioned by the Wireless Broadband Alliance says the number of private Wi-Fi internet access nodes in homes and offices will increase from 345 million today to 646 million by 2015. If that increase spreads evenly over all populated areas, it would lead to a doubling of London's node density, bringing the whole city up to the level of the area around King's Cross Station. More likely, future growth will fill in the density "valleys", increasing the area more than the intensity of congestion (Informa/WBA, 2011). But as MASS indicates, node density is less of a contributing factor to congestion than the amount of data relayed by each node, and for that we refer the reader to Cisco's forecast of a nearly 5-fold increase in Wi-Fi traffic in Europe during the 2010-2015 time frame.

In the early days of Wi-Fi, the vast majority of nodes connected computers to the internet. That is no longer the case. The number of internet access nodes just cited is but a fraction of the one billion Wi-Fi devices now in use.[43] Global sales of Wi-Fi equipped consumer electronic devices are expected to reach three billion in 2013, and 3.5 billion in 2014, dominated by cell phones, game consoles, DTTs, digital cameras, media players, e-readers and picture frames.[44] But it is not only numerical growth which causes concern. More than 700 million Wi-Fi devices sold this year implement the 802.11n standard, which does not co-exist well with the older 802.11b devices.[45] The width of "n" Wi-Fi channels (40MHz v 20 MHz for the "b" standard) means the impact on older models can be severe. On the other hand, since most "n" models come with "dual band" capability, their popularity is accelerating the migration of RLANs from 2.4 to 5 GHz. *PC Magazine* recently predicted

[43] Kerner, S. M., Wi-Fi 2015: Where is wireless networking going?, Wi-Fi Planet, 28 April 2010, http://www.wi-fiplanet.com/news/article.php/3879171

[44] Lance Whitney, More people buying Wi-Fi enabled devices, CNet.com, 4 May 2010, http://news.cnet.com/8301-1035_3-20004088-94.html; In-Stat Research, Digital TVs, Blu-Ray Players and Portable Media Players Drive Adoption of Wi-Fi in Consumer Electronics, 3 May 2010, http://www.in-stat.com/press.asp?ID=2776

[45] Stephen Lawon, In-Stat: Faster Wi-Fi will grow rapidly, IDG News (via PC World), 2 November 2011 - http://www.pcworld.com/article/242991/instat_faster_wifi_will_grow_rapidly.html

that "by the end of 2012, single-bands may be the routers left collecting dust in warehouses and retail shelves".[46] So while they add to the congestion at 2.4 GHz, this could be temporary as 802.11n routers provide an "exit path" to 5 GHz.

Our survey of NRAs[47] found that 11 out of 26 said they had reports of urban congestion problems in the 2.4 GHz band. But their responses to this information varied. The situation seems most serious in Poland, because of the large numbers of people who have internet access through outdoor Wi-Fi networks deployed by service providers (IDATE, 2009). Another 11 NRAs thought there was evidence of the 5 GHz band attracting more users. But overall, the NRAs' knowledge about occupancy levels in licence-exempt bands is limited. None – except for Ofcom in the UK – had monitored any of the five bands used by RLANs. 21 of the 26 who responded said they had no data about occupancy in licence-exempt spectrum and many thought that it was beyond their remit to know.

Considering the rapid expansion of licence-exempt band exploitation, this attitude seems complacent. It also shows the extent of "regulatory capture": when the subjects of regulation – licensees – are perceived by the regulator as clients, rather than the public, who are the actual clients. This indifference to conditions in licence-exempt spectrum is mirrored in the ITU, which omitted the bandwidth needed to support data offloads from their estimate of the spectrum requirements for IMT-Advanced. Our research, on the other hand, indicates that there will be a rapid increase in band utilization at 2.4 and 5 GHz over the next 5-10 years, owing to:

- The explosion in video streamed to tablets, wall-mounted flatscreen displays, laptops and other portable internet access devices via Wi-Fi.
- The "exaflood" of data transfers and offloads from cellular networks to Wi-Fi.
- A general proliferation of Wi-Fi equipped consumer electronic devices: The Wi-Fi Alliance certified more than 3,500 new products in 2011, compared to 9,000 during the previous 10 years.[48]

While MASS did not recommend that use of the 2.4GHz band should be limited to Wi-Fi, we believe it is worth considering the option of distinguishing wireless broadband access devices (WAS/RLANs) from other SRDs in shared access spectrum and according them higher status.[49] Our already extensive and still-growing dependence on this form of broadband access enables participation in the Information Society but it is precarious. In the next chapter we suggest a response to this problem.

## 2.7. Technology and market trends affecting demand for spectrum

> ...our conception of what's possible through wireless communication has been radically restricted by radio engineering practice. The limits we take for granted aren't dictated by the laws of physics. They are artefacts of the way we design systems. Wi-Fi and other unlicensed technologies are just the first example of what can happen when we start to relax our

[46] Lynn, S. (2012) 10 Wi-Fi Predictions for 2012, PC Magazine, 3 January, http://www.pcmag.com/article2/0,2817,2398093,00.asp

[47] 26 of the 27 NRAs responded to our questionnaire.

[48] Wi-Fi Alliance (2012) Wi-Fi innovations and user enthusiasm propel continued sales growth, press release, 10 January, http://www.wi-fi.org/media/press-releases/wi-fi%C2%AE-innovations-and-user-enthusiasm-propel-continued-sales-growth

[49] "Even if the legal environment indicates that the CUS [collective use of spectrum] approach falls under the non-interference/non-protection regime, the requests for more protection and better Quality of Service are major trends." RSPG (2011), p. 28.

> assumptions. And we're going to need more such breakthroughs to keep up with skyrocketing demand for wireless data... 50

The two most significant trends affecting demand for spectrum are the extraordinary growth of cellular mobile telephony and the proliferation of licence-exempt short-range devices. Both represent different approaches to spectrum sharing and they converge in the smart phone, which is now the main driver of spectrum demand in Europe.

### 2.7.1 Cellular's success

The basic concept of cellular network architecture is to provide a telecommunication service throughout an area by deploying a matrix of wireless base stations, each serving a limited area or "cell". The service zone of each base station is contiguous with the cells of adjacent base stations and with minimal overlap. That makes it possible to re-use frequencies with minimal interference.[51] Where there are high concentrations of users – in city centres, for example – cells can be made smaller, to enable more re-use of frequencies and support more simultaneous communication sessions. As long as each base station has its own "backhaul" link to the telecommunications grid, cell size reductions can continue more or less indefinitely, as the introduction of picocells and femtocells shows (the latter having a range of about 10m).[52] The ability to accommodate growing demand by increasing cell density, while the base stations coordinate the handsets' frequency use, makes this architecture very attractive from a spectrum management perspective: the network assumes responsibility for coordinating the frequency use of all connected handsets and the number of simultaneous communication sessions that can be supported is technically unlimited, even with a limited allocation of frequencies.[53]

Unfortunately, the cost and complexity of cellular networks increase geometrically as the number of base stations and backhaul links increases. Thus, economics limit network capacity even when the availability of frequencies does not. The optimum configuration for a specific network depends on market details – the number of subscribers, their communication habits, their handsets' performance, the costs of base stations, backhaul links and spectrum – as much as on engineering calculations. So while the spectrum requirements of cellular networks are elastic (since the amount of frequency re-use can vary), there is always a configuration which minimizes the combined cost of spectrum and infrastructure. This is what network operators seek in order to offer a competitive price for their services while still earning a profit. So when cellular network operators say they

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[50] Werbach, K. (2011) The potential for wireless breakthroughs, Werblog, 28 July, http://werblog.com/2011/07/the-potential-for-wireless-breakthroughs/

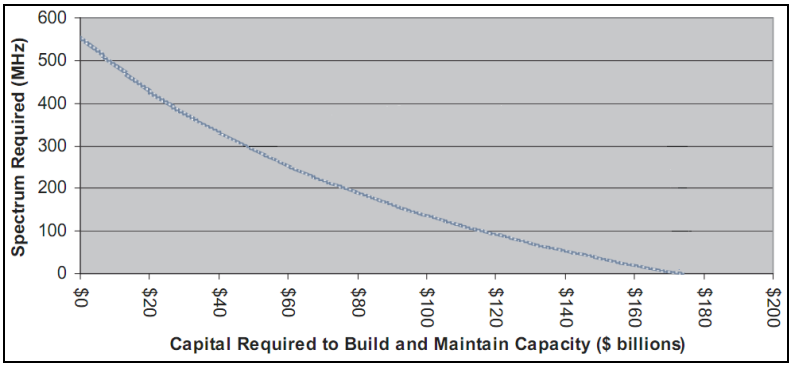
[51] Modern cellular systems are more sophisticated than this description suggests, with cells being "sectorised" to further increase frequency re-use.

[52] Even smaller cells are available but their market impact so far has been negligible. At the start of 2011 Ubiquisys, a leading producer of femtocells, introduced the world's first *attocell*: "Designed primarily for people travelling abroad, it enables mobile calls to be made and received as though in their home country…In some countries its range will be just 5mm, in other countries, it could cover a whole room...." Ubiquisys press release, 26 January 2011, http://www.business-wire.com/news/home/20110126005110/en/Ubiquisys-Announces-World%E2%80%99s-Attocell-Personal-Femtocell-iPhone

[53] As cell size approaches zero, the number of times that frequencies can be re-used approaches infinity – but so does the number of backhaul links needed for the base stations. In practice, India is the best demonstration of the bandwidth efficiency of cellular network architecture. There, one of the world's smallest cellular frequency allocations supports over 850 million mobile phone subscriptions. As a consequence, the average distance between base stations in Mumbai and Delhi is less than 100m, while in Berlin, for example, it is over 300m. Applying the ITU's recommended measure of spectrum efficiency, one finds that India's GSM networks are approximately 9 times as efficient as Europe's. See Lewin *et al*, 2008, pp 9-10.

need more spectrum, they are actually expressing a business judgment that additional spectrum is likely to cost them less than additional infrastructure. We will return to these points when discussing 4G.

Figure 2.7. Investment trade-off between spectrum and infrastructure, 2014




The graph in Figure 2.7, adapted from one produced by the FCC, shows that cellular capacity requirements in 2014 can be achieved with different combinations of infrastructure and spectrum. With an additional 300 MHz of spectrum, infrastructure costing about $50 billion is needed; with an additional 100 MHz of spectrum, infrastructure costing $115 billion is needed. So if 200 MHz of additional spectrum is likely to cost less than $65 billion, then it is a rational investment for network operators. Interestingly, the FCC's "indifference curve" suggests that if cellular networks in the US invest about $175 billion in additional infrastructure, they would need no additional spectrum in 2014 (OBI/FCC, 2010).

### 2.7.2 Small cells

As noted above, shrinking cells down to very small dimensions requires a miniature base station – a femtocell – which interacts with handsets in the same way as larger cell sites, but only within a range of about 10m. Femtocells are a clear example of "geographic sharing" of spectrum. They were developed mainly to boost localized signal strength and improve cellular network coverage indoors. But carriers now value them more for expanding the capacity of their network through frequency re-use, and even more for diverting data traffic from the carrier's own infrastructure to backhaul links provided by subscribers. For these reasons, many cellular carriers encourage their subscribers to buy femtocells, but so far uptake has been slow. Worldwide, about 1.3 million femtocells were distributed in 2010, according to ABI Research.[54] IDATE, meanwhile, predicts a "cumulative total of 39.4 million deployed units by 2015...".[55] Informa is more optimistic, predicting an installed base of 48 million by 2014.[56] Either way, these numbers are small compared to the number of new Wi-Fi access points likely to be deployed in the same period.

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[54] Kaul, A. (2009) Femto market looks to 2010 and beyond, ABI Research blog, 26 November, http://www.abiresearch.com/research_blog/1406; 2010 Femto market inhibited by legislation, ABI Research press release, 11 February 2011, http://www.abiresearch.com/press/3615-2010+Femto+Market+Inhibited+by+Legislation

[55] Major telecom equipment vendors, operators showing greater interest in femtocell market, IDATE News 562, 6 September 2011, http://www.idate.org/en/News/Femtocells_692.html

[56] Informa (2011), Femtocell Market Status Q1, http://femtoforum.org/femto/pdfsend01.php?file=023%20Informa%20Femtocell%20Market%20Status%20Q1%202011.pdf

From the end-user's perspective, Wi-Fi is a better deal, especially for web browsing, video-streaming and file-sharing (the handset applications responsible for most data traffic).[57] But for the carrier, Wi-Fi offers both benefits and risks. It reduces backhaul traffic on the network and thus reduces operating costs. But it also lets subscribers make calls using voice-over-Wi-Fi and bypass the cellular network's quotas and fees on data transfers. So even though many carriers encourage Wi-Fi for offloads, to the point of operating their own hotspots or arranging for their subscribers to have preferred access to others', they remain wary of Wi-Fi because ultimately it threatens their revenue stream. The basic problem is that a femtocell costs more than a Wi-Fi access point (the industry is struggling to bring the cost of a femtocell down to $100), and the carrier benefits more than the user. Therefore, a growing number of carriers subsidize their subscribers' purchases of femtocells. France's SFR has started giving them for free.[58]

The cellular industry uses the term "small cells" for femtocells, picocells and the Wi-Fi hotspots used by mobile handsets. Small cells are essential to cellular's future. With data traffic constantly growing, there is a need for much more re-use of frequencies. When we spoke earlier of the number of cell sites increasing "geometrically" to keep up with growing demands on network capacity, the implications may not have been clear. Even with more allocated spectrum, more offloading and higher spectrum efficiency, the Mobile Experts consultancy predicts that 10 times as many base stations will have to be deployed "as we move into LTE and LTE-Advanced networks".[59] NTT DOCOMO's Yoshihisa Kishiyama calculates that to keep up with demand, by 2020 there will have to be 25-50 times as many base stations as there are today.[60] These will mostly be small cells. How many are we talking about? Picochip's CTO Doug Pulley figures that by 2015, there will have to be 10 million more small cells in the world, 70,000 of them in London.[61] And each will need backhaul.

While everyone in the cellular industry recognizes the need to deploy more small cells, not everyone thinks femtocells are the answer. Integrating them into a carrier's billing and management systems is labour intensive, and the benefits of frequency re-use can be undermined by poor spectrum management: since femtocells use the same frequencies as other cell sites (rather than the Wi-Fi frequencies at 2.4 and 5 GHz), bad channel selection by a femtocell can create a "coverage hole" and interfere with nearby base stations. Femtocells registered with different networks are often located near each other in office buildings. In that situation, the "right" frequency choice for one network may be the wrong choice for others.[62] "A top AT&T executive told Wall Street several years ago they

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[57] According to Allot (2011), in the first half of 2011, 39% of all mobile data use was streaming video; 29% was file sharing; 25% was web browsing; 4% was VOIP and instant messaging; and 3% was a mix of other applications.

[58] Gabriel, C. (2011) SFR offers Europe's first free femtocells, Rethink Wireless, 26 September, http://www.rethink-wireless.com/2011/09/26/sfr-offers-europes-free-femtocells.htm

[59] Madden, J. (2011) Spectral efficiency doesn't cut it anymore, Mobile Experts blog, 4 January, http://mobile-experts.blogspot.com/2011/01/spectral-efficiency-doesnt-cut-it.html

[60] Cited by Jens Zander in his synopsis of Yoshihisa Kishiyama's presentation at the first Next Generation Mobile Networks Alliance Innovation Day in Stockholm, Sweden, 15 September 2011, The Unwired People Forum, http://theunwiredpeople.com/ngmn-innovation-day-in-stockholm/

[61] Picochip (2011) London needs 70,000 small cells for world-class mobile broadband, press release, 27 September, http://www.picochip.com/news/203/

[62] A possible solution to the problem of femtocell interference into macrocells would be to shift femtocell frequency use into UHF white spaces (if unlicensed use is authorised). See Peng, F., *et al.* (2011) "Using TV White Space for Interference Mitigation in LTE Femtocell Networks", IET International Conference

would massively deploy femtocells. Spending $500M on a cloud of 10M femtos would provide equivalent bandwidth to buying $3-4B of spectrum."[63] But in the first half of 2011, AT&T drastically reduced deployments of femtocells, citing interference problems. Håkan Eriksson, chief technical officer of the world's largest network infrastructure vendor, Ericsson, is even more critical:

> The femtocell solves no problem from my viewpoint… Even worse, the femtocell will, somehow at least, interfere with the macro network that is close by. What will happen is that the industry will realize that femtos are a bad idea… Perhaps by 2020 there will only be LTE and Wi-Fi, with LTE providing the wide-area and '802.11 something' for the home… (Rasmussen, 2011).

Not surprisingly, Ericsson recently introduced "Network Integrated Wi-Fi" as their alternative to femtocells.[64] We will have more to say about cellular/Wi-Fi integration later.

### 2.7.3 The generation game in mobile – 2G, 3G, 4G

Fortunately, there are other ways to increase capacity than by expanding spectrum allocations, increasing cell density or promoting femtocells. Cellular networks have already evolved through several radio interface "generations". Each improved the signal structure to increase carrying capacity (pack in more bits per second per Hz), while shifting incrementally from voice to data optimization. Analogue mobile telephony (NMT) can be considered the first generation while GSM is the second (2G). The current stage of development, 3G, is called IMT-2000 by the ITU, or UMTS (the Universal Mobile Telecommunications System) in Europe.[65]

UMTS was intended to replace GSM eventually. The proliferation and popularity of smart phones and tablets is certainly accelerating switchover, but UMTS coverage is still spotty[66] and since enough subscribers find GSM adequate for their needs, the 2G-to-3G transition is unlikely to be completed before the next generation of cellular technology arrives. As a result, carriers may find themselves operating 2G, 3G *and* 4G networks "for the foreseeable future".[67] That is an inefficiency which increases spectrum requirements.

Recognizing this possibility, and to smooth the transition to newer technologies, the deployment of 3G and 4G networks in any band previously designated for 2G is now

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on Communication Technology and Application (Beijing, China), http://conference.bupt.edu.cn/iccta2011/article_web/uploadArticles/225-20110729212841.pdf

[63] Burstein, D. (2011) Femto failure frustrating AT&T, DSL Reports, 6 July, http://www.dslreports.com/shownews/Femto-Failure-Frustrating-ATT-115029

[64] Network integrated Wi-Fi solution by Ericsson, press release, 27 September 2011, http://www.reuters.com/ article/2011/09/27/idUS67086+27-Sep-2011+HUG20110927

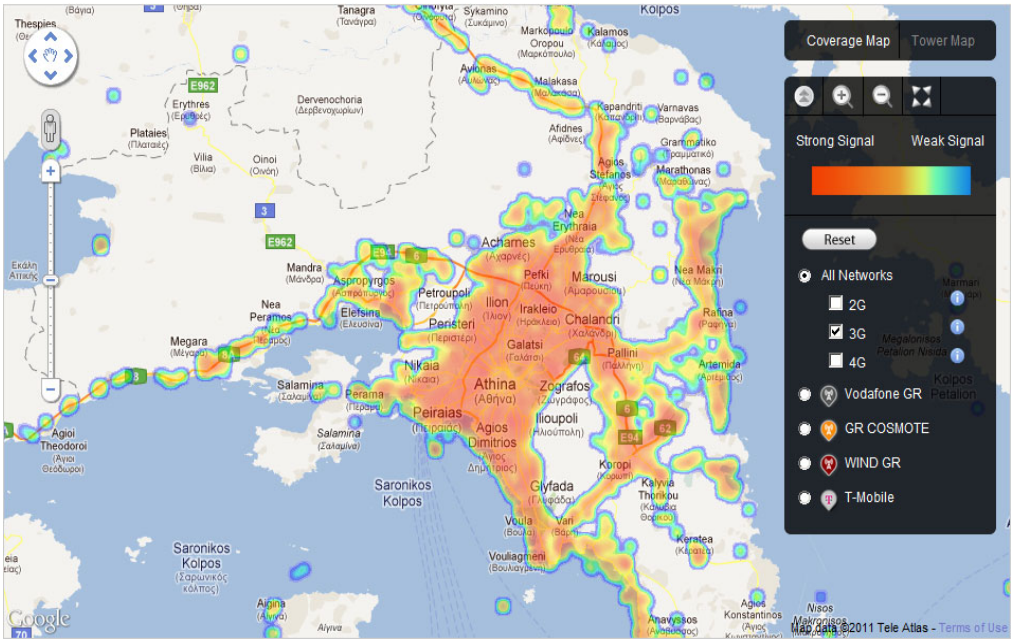
[65] UMTS is Europe's response to ITU-R Recommendation M.1457: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2000 (IMT-2000), http://www.itu.int/rec/R-REC-M.1457/en

[66] Despite 3G operators' claims that their networks cover 97% of the UK population, 44,600 volunteers in a BBC survey used their handsets to check 42 million locations throughout the UK and found a 3G signal 75% of the time. A similar survey by OpenSignalMaps's 31,700 UK volunteers found a 3G signal 58% of the time. Wakefield, J. (2011) 3G mobile data network crowd-sourcing survey, BBC News, 24 August, http://www.bbc.co.uk/news/business-14574816. OpenSignalMaps, http://opensignalmaps.com/

[67] "From the review conducted by BEREC-RSPG it appears that the majority of countries do not have a clear indication as to how long GSM will continue to operate, but the general consensus across all the responses is that GSM (at 900 MHz and 1800 MHz) will still continue to be used for the foreseeable future." RSPG BEREC Report on Competition: Transitional Issues in the Mobile Sector in Europe, BoR (11) 07/RSPG10-351 Final (February 2011), page 11, http://rspg.groups.eu.int/documents/documents/meeting/rspg24/rspg10_351_transitional_issues.pdf

allowed in Europe, and member states are incorporating that decision into their cellular licence rules.[68]

Figure 2.8. 3G coverage in Athens, Greece




Source: OpenSignalMap's crowd-sourcing application for Android phones (September 2011).

### 2.7.4 IMT, IMT Advanced, LTE and Mobile WiMAX

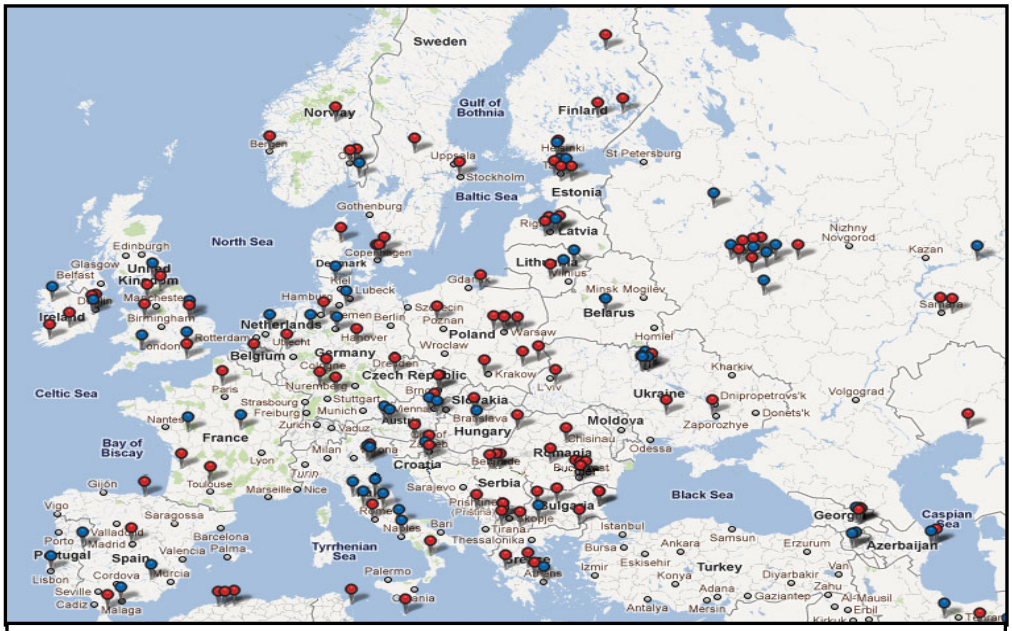
The next stage of cellular mobile development, 4G, aims for a giant leap in performance.[69] Performance targets include a peak spectrum efficiency of 15 bit/s/Hz near a base station (the spectrum efficiency of UMTS is just 1-2 bit/s/Hz). Data transfer rates of 1 Gbps for the low-mobility/nomadic scenario and 100 Mbps for the high-mobility scenario are key benchmarks in the specification. It is important to note that 4G is the cellular radio interface for "IMT-Advanced", an ambitious expansion of the cellular business model to encompass satellite links, WLANs, sound and video broadcasting, tethered dirigibles, mesh networks, narrowband M2M and virtually any other type of wireless digital network. This proposal is developing under the auspices of the ITU to support a wide range of scenarios, from "nomadic/low mobility" (pedestrians standing or walking) to "high mobility" (vehicles moving at 120-350 km/hour). Although some people use IMT-Advanced and 4G interchangeably, and 4G is increasingly used to market what are actually improved 3G technologies, we will use 4G in this study to refer to the cellular radio interface and IMT-Advanced to refer to the heterogeneous "network of networks" that would extend the traffic management capabilities and billing services of today's cellar networks. The term "IMT" is used to refer to 2G, 3G and 4G: any and all of them.

[68] Directive 2009/114/EC of the European Parliament and of the Council of 16 September 2009 amending Council Directive 87/372/EEC on the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the Community, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:274:0025: 0027:EN:PDF.

[69] Report ITU-R M.2134: Requirements related to technical performance for IMT-Advanced radio interface(s), 2008, http://www.itu.int/publ/R-REP-M.2134-2008/en

In October 2010, the ITU announced that two radio interface technologies – *LTE-Advanced* and *WirelessMan-Advanced*[70] – "successfully met all of the criteria established by ITU-R for the first release of IMT-Advanced".[71] The first demonstration of LTE-Advanced in Europe was conducted by Ericsson in Sweden in June 2011. A peak data transfer rate of more than 900 Mbps was achieved between the base station and a moving vehicle. Full-scale equipment production is could start in 2013.[72] The UMTS Forum says, more cautiously, that the market debut of LTE-Advanced is "planned for 2015" (UMTS, 2011). Two weeks after Ericsson's demonstration, the first successful field test of WirelessMan-Advanced took place in Tokyo.[73] The first dongles implementing this standard are expected "in late 2011" with "widespread commercial deployments starting in 2012".[74]

Figure 2.9. WiMAX networks in Europe, 18 August 2011




Source: WiMAXmaps.org

Although WiMAX seemed to represent the future of "converged" networks, its growth has been hemmed in by cellular on one side and by Wi-Fi on the other, so its fate is uncertain.

70 WirelessMan-Advanced is the new name for Mobile WiMAX Release 2.

71 ITU paves way for next-generation 4G mobile technologies, 21 October 2010 – http://www.itu.int/net/pressoffice/press_releases/2010/40.aspx

72 Corner, S. (2011) Ericsson achieves almost 1Gbps in first LTE Advanced demo, ITWire, 28 June, http://www.itwire.com/business-it-news/technology/48164-ericsson-achieves-almost-1gbps-in-first-lte-advanced-demo

73 Ayvazian, B. (2011) WiMax and LTE: Convergence and coexistence, Light Reading, 26 July, http://www.lightreading.com/document.asp?doc_id=210453

74 WiMAX Act 2: 802.16m Provides Evolution Path to 4G, WiMAX.com press release, 3 February 2010, http://www.wimax.com/features/wimax-act-2-80216m-provides-evolution-path-to-4g

**Box 2.1. WiMAX – between a rock and a hard place**

Cellular and WiMAX are usually seen as rivals or complements, though in the future they might converge since the ITU recognizes WirelessMan-Advanced (the new name for WiMAX Mobile 2) as one of the radio interfaces satisfying the technical requirements for IMT-Advanced. In 2005 a new version of the standard supporting mobility was released, adding options for hand-offs, MIMO, optimizations for coverage or capacity, etc, and about 60% of the existing fixed WiMAX networks migrated to the mobile standard even when most of their subscribers continued accessing the network from fixed locations. This led to confusion about whether WiMAX networks are mobile or fixed. In fact, they are mobile and fixed converged. WiMAX's versatility makes it suitable for many applications, including mobile voice, fixed point-to-point (backhaul), "hotspot" and wide-area (point-to-multipoint) internet access.

When WirelessMan-Advanced equipment is available, it can be deployed in any band identified for IMT.[75] However, whether it will be deployed is another matter. WiMAX already has a head start in the 3.4-3.6 GHz band. But cellular network operators strongly back LTE-Advanced and the wireless ISPs who support WiMAX do not have the financial resources to outbid cellular operators for licences in the IMT bands, so WirelessMan-Advanced may not gain traction outside the C-band.

According to the WiMAX Forum, there are 163 WiMAX networks in Europe: 141 licences were awarded in the 3.5 GHz band, 45 licences in the 2.5 GHz band. Most of the latter are in Russia.[76] The largest networks are in Russia, Czech Republic, Finland, Lithuania and Hungary. A recent survey of 28 CEPT member states found that more than 12,500 WiMAX base stations have been deployed, with the number "growing very rapidly."[77] Senza Fili (2010) predicts that WiMAX will attract 15.3 million subscribers in Europe and Russia by 2014. That may be optimistic if IDATE was correct in reporting a total of 1.8 million WiMAX and "wireless local loop" subscribers in Europe at the start of 2009.[78] (They did not include the estimated 500,000 subscribers in Russia.) The most difficult market for WiMAX remains Western Europe, according to Senza Fili (2010). There it is perceived as a service for areas where DSL and cellular coverage is poor – ie in areas of low population density, which DSL and cellular network operators find unattractive. Unfortunately, WiMAX has a disadvantage in filling that niche: 3.5 GHz is too high a frequency range for good coverage of rural landscapes. But WiMAX does have advantages:

• WiMAX licences cost much less than cellular licences, reducing the start-up costs to be recovered from subscribers.[79]

• WiMAX's information carrying capacity is comparable to LTE's but the base stations cost about 75% less.[80]

• The 2010 update of the mobile WiMAX standard added sophisticated interference avoidance and coexistence techniques, enabling polite operation in licence-exempt spectrum. That means even lower start-up costs and no delays due to auctions and beauty contests. But, as we noted, WiMAX licences are not expensive, so any saving in the cost of spectrum access due to licence exemption is minor compared to the costs added by the power output limits imposed on licence-exempt equipment: more base stations are needed to equal the coverage of a licensed network.

• Many EU Member States subsidize the rollout of wireless broadband into areas beyond the reach of DSL and cellular. WiMAX is usually a cost-effective alternative.

It is difficult to predict WiMAX's future. Much depends on whether it converges with LTE Advanced, and whether handset and tablet makers expand the number and variety of products with WiMAX support built in. Currently there are few choices and some suppliers have decided to concentrate on LTE. And as WiMAX in Western Europe has a mainly rural niche, much also depends on state aid decisions.

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[75] ITU defines the future of mobile communications, press release, 19 October 2007, http://www.itu.int/newsroom/press_releases/2007/30.html

[76] Data on the frequency distribution comes from Maravedis Research, 2006.

[77] The quote and the information about network size comes from Draft ECC Report 173 - Fixed Service in Europe: current use and future trends post-2011, http://www.bmvit.gv.at/telekommunikation/international_eu/ECC/ECC_Report_173.pdf

[78] IDATE, 2009. In some countries "wireless local loop" means ISP links using Wi-Fi, in others it means point-to-point microwave using a proprietary standard.

[79] According to Maravedis (2006), the average cost/MHz/pop of a WiMAX licence in Europe was $.006, compared to the average for a European 3G licence of $1.01/MHz/pop, according to *PolicyTracker's* analysis (Sims, 2011). The cost average of WiMAX licences was significantly reduced by Spain, Austria, Poland, Ireland, Denmark and Sweden, where the licences were almost free, but with annual fees. However, most WiMAX licences are for higher frequency bands than 3G's so lower spectrum costs partly compensate for reduced signal range.

[80] The average cost of an LTE base station in 2011 was €51,850, according to Arieso. The average cost of a 3.5 GHz WiMAX base station was €13,546, according to WiMAX360 and other sources. The price range of both types of base station vary widely, however, and volume discounts are common.

For years there has been hopeful speculation about converging the LTE-Advanced and WirelessMan-Advanced standards. In fact they are similar, so merging them would not be technically difficult.[81] But there are intellectual property issues and intense rivalry between the two standards' backers. Roaming without compatibility problems, reduced equipment costs due to greater economies of scale, and more freedom of choice when users want to change the network to which they subscribe, are all predictable benefits from having a single standard. But if that is to be achieved, it must happen soon since the development of commercial equipment has already begun.

### 2.7.5 Future spectrum demands for cellular mobile

Thirty years ago, few people foresaw that cellular mobile technology would permeate society, catalyzing economic productivity and social cohesion. We also did not expect that, even after reaching 100% penetration,[82] a second stage of traffic growth would follow, based on internet access and the ever-increasing memory capacity, display quality and functionality of handsets. The success – the indispensability – of cellular is now well-established, so attention is shifting toward the future, as forecasts of rapidly growing demands for bandwidth accumulate.

According to IDATE, data traffic surpassed voice in Europe's cellular networks in 2009, and "voice traffic growth is expected to remain limited compared to the explosive growth in data traffic from 2010 to 2020" (UMTS, 2011). The widely-followed Cisco Visual Networking Index suggests how explosive that growth may be: the June 2011 edition predicts that between 2010 and 2015, mobile data traffic will have a compound annual growth rate of 102% in Central/Eastern Europe and 91% in Western Europe (Cisco, 2011).

The ability to adapt to growing demand is inherent in cellular network architecture. However, the adaptation process is slower than the current rate of demand growth, so all eyes are on the operators' response. The upsurge in mobile internet access cannot be met with additional capacity quickly enough from the allocation of more spectrum, building more base stations or upgrading to 4G, even though all of these are needed to sustain the development of mobile broadband and advanced telecommunication services over the long term.

Fortunately, nearly all smart phones and tablets now have several different radios built in, including Wi-Fi, so they are not just cellular devices anymore. With growing numbers of 3G operators imposing download caps, throttling subscribers who use the most bandwidth, and cancelling unlimited data plans, users are shifting their portable internet access to Wi-Fi whenever possible, and many carriers accept and endorse this trend. In the next section we will explore the relationship between licence-exempt spectrum and cellular. For now we just note that a new report on mobile data traffic drafted by ITU Working Party 5D says: "A significant proportion of smart phone traffic is generated indoors; accordingly, we estimate that between 80% and 90% of this traffic is routed over Wi-Fi and fixed broadband networks".[83] This is why we emphasize that smart phones can

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[81] Judge, P. (2008) First LTE Base Station Runs WiMax, Too, TechWorld, 5 February, http://www.pcworld.com/article/142150/first_lte_base_station_runs_wimax_too.html

[82] According to the Digital Agenda Scoreboard, the penetration rate for mobile subscriptions in the EU reached 124.2% in October 2010.

[83] SWG IMT.UPDATE, Annex 3: Detailed Information on Usage and Mobile Application Trends, ITU Working Party 5D, Document 5D/TEMP/568-E (14 July 2011), http://www.itu.int/md/R07-WP5D-110707-TD-0568/en

no longer be regarded as just cellular handsets and the spectrum needed for offloads cannot be ignored.

According to the European Communications Office's Frequency Information Service,[84] 781.5 MHz of spectrum is currently designated for cellular mobile networks. As part of the "digital dividend" from the switch-off of analogue TV broadcasting, an additional 72 MHz in the 790-862 MHz band was allocated to "mobile/fixed communications networks" (MFCN), a broad new "converged" service category intended to include cellular. This band is expected to become available by 2015 in the CEPT countries which do not reserve the frequencies for digital broadcasting or other services.[85]

**GSM/UMTS allocations (from the ECO Frequency Information System)**

880 - 915 MHz
925 - 960 MHz
1710 - 1785 MHz
1805 - 1880 MHz
1900 - 1980 MHz
2010 - 2025 MHz
2110 - 2170 MHz
2483.5 - 2690 MHz
3400 - 3600 MHz

The ITU produced a series of reports in 2006 to pave the way for global expansion of the allocations for cellular mobile at WRC-07. Determining an appropriate size for the expansion required forecasts of market demand for mobile broadband services in the 2010-2020 timeframe. These forecasts were translated into network capacity and performance targets, which became inputs for calculating the spectrum requirements. The following tables are adapted from "Report ITU-R M.2078" (ITU, 2006c). Note that existing 2G and 3G allocations are included in the future requirements for 2G and 3G, while allocations for 4G would be new. Note, too, that the ITU assumes the offloading of cellular data traffic to Wi-Fi and other RLANs will continue through the forecast period:

Table 2.3. Ranges of predicted spectrum requirements (MHz)

Lower user density markets:

| | 1 network | 2 networks | 3 networks | 4 networks | 5 networks |
|---|---|---|---|---|---|
| **2G/3G** | 800 | 880 | 840 | 1120 | 1000 |
| **4G** | 480 | 560 | 720 | 800 | 1000 |
| **2G/3G/4G total** | 1280 | 1440 | 1560 | 1920 | 2000 |

Higher user density markets:

| | 1 network | 2 networks | 3 networks | 4 networks | 5 networks |
|---|---|---|---|---|---|
| **2G/3G** | 880 | 880 | 960 | 1120 | 1200 |
| **4G** | 840 | 880 | 1020 | 1120 | 1300 |
| **2G/3G/4G total** | 1720 | 1760 | 1980 | 2240 | 2500 |

### 2.7.6 Underestimation – impacts of product and technology development

Two further points should be noted. First, the above estimates are based on a market analysis using data from 2003-2005, ie before the impact of the Android operating system, the tablet form factor, the iPad, iPhone and similar handsets was felt. The ITU recently acknowledged that these forecasts are "too conservative".[86] The CEPT Electronic

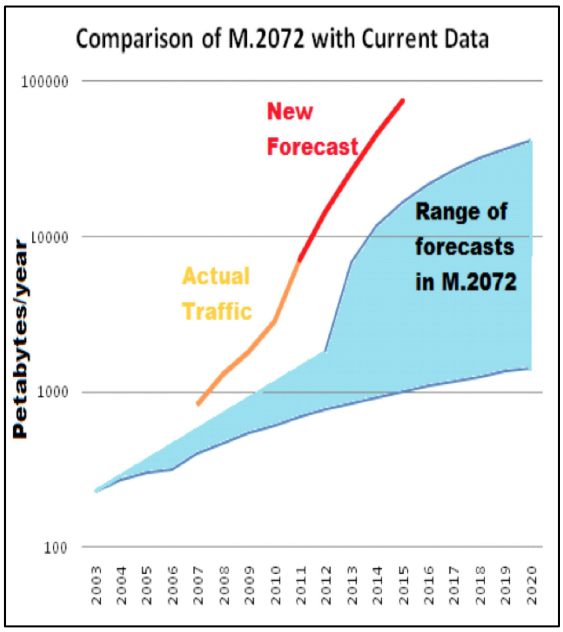
[84] http://www.efis.dk/

[85] ECC Decision of 30 October 2009 on harmonised conditions for mobile/fixed communications networks (MFCN) operating in the band 790-862 MHz, ECC/DEC/(09)03, http://www.erodocdb.dk/ docs/doc98/ official/pdf/ECCDec0903.pdf

[86] Ruismäki, R. (2011) Perspectives on future Mobile Broadband, presented at a series of regional workshops on IMT for the next decade organized by ITU-R Working Party 5D.

Communications Committee Project Team 1 (ECC PT1, which coordinates the development of the regulatory framework for IMT in Europe) confirms this, pointing out that the ITU's mobile data traffic forecast for 2010 is 30% lower than the levels actually measured in Europe that year, and the acceleration of traffic growth is much faster than predicted (see Figure 2.10 and note that it uses a logarithmic scale: the new forecast for 2015 is about 4 times the previous maximum forecast).[87]

Figure 2.10. Comparing the ITU's 2006 cellular traffic forecast with current data
Source: ITU (2011)




Second, the ITU estimate also does not include all the spectrum needed to support the 1 Gbps low-mobility/nomadic component of IMT-Advanced. They consider that a "hot-spot" application, requiring short-range access zones and no hand-offs, so licence-exempt spectrum is suitable: "existing RLANs will share a portion of the relevant total traffic. WRC-03 identified globally common spectrum for RLANs [in the 5 GHz band], which allows considerable capacity for such networks."[88] In other words, like today, most data transfers are likely to be offloaded, but the bandwidth needed for offloads was not calculated. There is a hint, however, that the volume could be sizable: "One Administration has made some estimates of nomadic spectrum and has shown that this could be more than 50% of the total [licensed] spectrum estimate".[89] That is a very large amount to leave out of the accounting.

In most European countries, 3 or 4 operators now serve the cellular mobile market. Most or all will want to evolve their networks to 4G, and some newcomers (eg from fixed telephony, cable television or wireless ISPs) might want to enter the market, too.[90] So the ITU's spectrum estimates for a 3-network market seem the relevant guide, even if the

[87] Liaison statement to CPG PTA on WRC-12 agenda item 8.2, CPGPTA(2011)036 (12 May 2011).

[88] Rep. ITU-R M.2078, page 6.

[89] Annex 3: Estimation of spectrum for nomadic applications, Rep. ITU-R M.2078, page 86.

[90] Watson, J. (2011) Belgian 4G auction attracts two potential new entrants, *PolicyTracker*, 24 October, https://www.policytracker.com/headlines/belgian-4g-auction-attracts-two-new-entrants

traffic forecasts are too low.[91] However, the European Common Proposals for WRC-07 opted for a one-network solution – perhaps because the 3-network spectrum requirement seemed unachievable: "In the case of the high user-demand scenario [the one-network] requirement is equivalent to additional spectrum of 1135 MHz".[92]

### 2.7.7 International spectrum agreements have yet to catch up

Except for high-data-rate/low-mobility activities which can use frequencies over 5 GHz, the ITU recommended that all new bands for IMT-Advanced should be between 400 MHz and 5 GHz – quite a challenge, since the amount needed is 34-43% of the entire range, or more, depending on which estimate is used. Specific "candidate" bands for expanding the IMT allocations were suggested in an ITU report.[93] These were the focus of discussions and decisions at WRC-07. All of the candidate bands are allocated to and used by other services, so Report ITU-R M.2079 began the review of compatibility, sharing and refarming issues which continues today in many countries. The bands identified by WRC-07 for Region 1 (which includes Europe) were 450-470, 790-862, 2300-2400 and 3400-3600 MHz.[94]

In contrast to 3G's success at WRC-00, the outcome of WRC-07 was disappointing for 4G:

- Most importantly, just 392 MHz of new spectrum was identified for terrestrial use by IMT in Europe – a small fraction of the amount needed to fulfil the ITU's spectrum estimate for a one-network market – an estimate now recognized as too low, and which does not take into account the spectrum needed for offloads.
- All the new IMT-identified spectrum is shared with other services. Some of the bands (450-470 MHz, for example) are crowded with assignments, so their near term availability for IMT is limited. Moreover, the chairman of the ITU workgroup on IMT band sharing, explained in an interview for this study that channel sharing with non-cellular systems is only practical in sparsely populated areas because LTE base stations use spectrum so intensively and in such wide channels.[95] This was known when the bands were identified at WRC-07, so Resolution 223 acknowledges that "for some administrations the only way of implementing IMT would be spectrum refarming, requiring significant financial investment…".[96]

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[91] The WINNER II project also assumed three complete, geographically overlapped networks. Ojala, J. *et al.* (2007) Spectrum Requirements for System beyond IMT-2000, WINNER II Deliverable D 5.10.2 v1.0, page 36, http://www.ist-winner.org/WINNER2-Deliverables/D5.10.2.pdf

[92] Addendum 4 to "European Common Proposals for the Work of the Conference", WRC-07 Document 10-E (July 2007) - http://www2.fcc.gov/wrc-07/rcp/cept/add10-4.doc

[93] Report ITU-R M.2079: Technical and operational information for identifying spectrum for the terrestrial component of future development of IMT-2000 and IMT-Advanced - http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2079-2006-PDF-E.pdf

[94] Resolution 224 (Rev.WRC-07). Strictly speaking, 3400-3600 MHz was not a regional allocation, but it was accepted by 82 countries, 41 of them in Europe. An additional 14 MHz was identified for countries implementing the satellite component of IMT, and 170 MHz for High Altitude Platforms supporting IMT (the HAP allocations mostly overlap the terrestrial IMT bands). See Resolution 221 (Rev.WRC-07).

[95] Interview with Michael Kraemer, Chairman of Sub-Working Group Spectrum Sharing, ITU Working Party 5D - IMT Systems, 1 December 2011. His views differ from the proponents of Authorised Shared Access with regard to the possibility of band sharing between IMT and other services.

[96] Resolution 223 (Rev.WRC-07): Additional frequency bands identified for IMT.

- Only 120 MHz of the newly identified spectrum for terrestrial IMT is globally harmonized.[97] Without the economies of scale and the roaming freedom enabled by global harmonization, achieving mass market success will be more of a struggle.
- Some delegations thought that the identification of bands in the 6-10.6 GHz range to support the high-data-rate/low-mobility component of IMT-Advanced should be added to the WRC-12 agenda. But others believed those requirements can be satisfied by the existing RLAN allocations at 5 GHz. The latter opinion prevailed, so the identification of additional spectrum for IMT is not on the WRC-12 agenda.

Failure to agree on more than 120 MHz of globally harmonized new spectrum for IMT at WRC-07 made it more important to identify *regionally* harmonized bands. At an ECC PT1 meeting in January 2008, Sweden's representative said, "it is paramount that CEPT develop and agree on harmonized spectrum arrangements for the bands 470-862 MHz and 3400-3800 MHz taking into account the estimated bandwidths for future terrestrial mobile broadband networks using up to 1000 Mbit/s data rates".[98] Thus, the UHF band for television broadcasting and half of the "C-band" came into play as possible extensions of the newly identified IMT bands. These extensions would include up to 580 MHz of additional spectrum. Work on replanning 3400-3800 MHz has started (EU, 2008) but we are far from consensus on the future of UHF. If 470-862 MHz is opened to IMT, a contiguous band from 450 to 862 MHz would be created. But what about DTT and white-space devices?

Before WRC-07, the European Commission had proposed that:

> use of the UHF band should not be 'frozen' by the present spectrum allocation situation but should be assessed in the light of the opportunities provided by new, efficient uses… [E]qual regulatory treatment of all spectrum used for electronic communication services is essential to foster constructive industry cooperation… Currently, the ITU Radio Regulations grant broadcasting services a higher regulatory status (a 'primary allocation') in the UHF band in Europe. Since additional spectrum for mobile services is being considered by WRC-07, a first step in the direction of more flexibility could be taken by upgrading the status of these services to the same status as broadcasting services at this conference.99

Most EU members arrived at WRC-07 opposing that position: to protect broadcasting, they wanted "no change" in mobile's status. But by the conference's end, the member states had agreed to a compromise to make mobile and broadcasting co-primaries at 790-862 MHz, though not below 790 MHz.

### 2.7.8 Integrating TV and mobile over broadband

The European television industry's initial reaction to the idea of "equal status" with mobile broadband was dismay. But the urge to find a peaceful solution quickly gained ground as

[97] Only the new 450-470 MHz and 2300-2400 MHz bands for IMT are globally harmonized.

[98] Meeting Document PT1(08)018: Frequency arrangements for IMT (10 January 2008). A Commission Decision of 21 May 2008 called for the designation of 3600-3800 MHz for IMT on a non-exclusive basis within 6 months, with 3600-3800 MHz similarly designated by 2012. (EU, 2008)

[99] Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: The ITU World Radiocommunication Conference 2007 (WRC-07), COM(2007) 371 final (2 July 2007), http://eur-lex.europa.eu/LexUriServ/site/en/com/2007/com2007_ 0371en01.pdf

broadcasters realized they had more to gain from broadband than from fighting it. In 2009, work began on "hybrid broadcast-broadband TV" to converge delivery systems. Then, in her address to the 2011 International Broadcasting Convention, the EBU's new Director General Ingrid Deltenre proposed a "strategic partnership":

> We need a partnership of broadcasting and wireless broadband. Each must be used, where it best meets the needs of the public. Broadcasting used for delivering the ever higher quality content to large audiences as the public demands. Broadband used as a partner when direct interactive services are needed for fewer users. I am not here to tell you what system this would be technically, this is a job for the engineers, but simply to say that it is the only realistic way ahead.[100]

The convenient fact that LTE's downlink signal is similar to DTT's led to meetings between the Digital Video Broadcasting Project and the 3G Partnership Project to discuss how to bring their audiovisual delivery systems closer together. A bridge is now being built between the standards known as DVB-NGH (Digital Video Broadcasting–Next Generation Handheld) and eMBMS (the LTE Evolved Multicast Broadcast Multimedia Service). A study by Ericsson justifies even tighter integration:

> it is possible to support TV services with 84 MHz of spectrum via LTE MBMS, in contrast to the 300 MHz used by today's ATSC TV broadcast system. This approach can be realized in a cost-effective manner by re-using existing mobile network infrastructures.[101]

In other words, using existing cell sites to broadcast digital television could yield a second "digital dividend". IP datacasting is already being used to stream TV over LTE in Germany.[102]

Meanwhile, ITU activities continue, with "Working Party 5D - IMT Systems" taking the lead. Their work focuses on "refreshing the vision and market forecasts for IMT" to support new and improved estimates of the spectrum needed to develop and implement this family of technologies during the next 10 years. They are also firming up the specifications of the radio interfaces, conducting sharing and compatibility studies, looking for new candidate bands and preparing a "draft agenda" for WRC-15.

## 2.8. The future radio landscape

Here we consider the impacts of IMT-Advanced and other radio technologies on the future radio landscape.

### 2.8.1 IMT-Advanced – not just a new cellular interface

As noted above, IMT-Advanced is much more than a new radio interface: it is "a combination of different radio access techniques… [which] incorporate cellular, wireless LAN, digital broadcast, satellite and other access systems… connected via flexible core

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[100] Deltenre, I. (2011) Broadcast and broadband: how can we meet Europe's media needs? speech at IBC-11, Amsterdam, 9 September, http://www.ebu.ch/CMSimages/en/DG%27s%20speech%20finalised%20_tcm6-72531.pdf

[101] Jörg Huschke, et al. (2011) Spectrum Requirements for TV Broadcast Services using Cellular Transmitters, IEEE International Symposium on Dynamic Spectrum Access Networks (DySPAN), http://www.ericsson.com/res/thecompany/docs/journal_conference_papers/wireless_access/p22-huschke.pdf

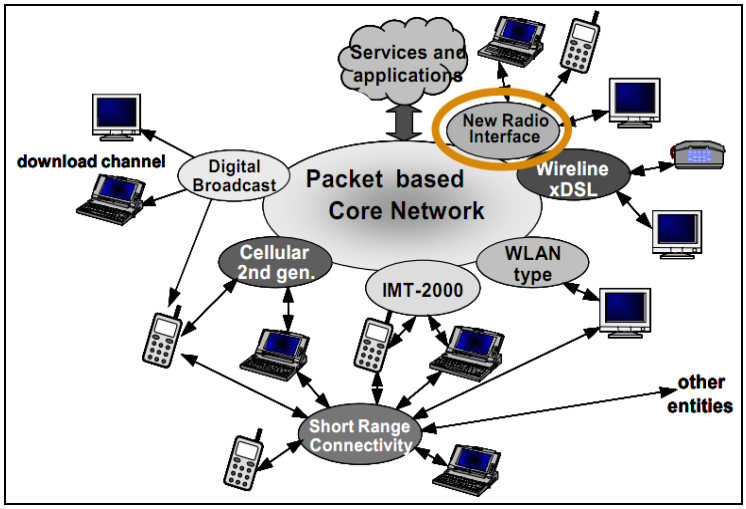
[102] Briel, R. (2011) Vodafone Germany to bring TV to LTE, Broadband TV News, 2 September, http://www.broad bandtv news.com/2011/09/02/vodafone-germany-to-bring-tv-to-lte/

networks.… In this way, an individual user can be connected via a variety of different access systems to the networks and services he desires…" (ITU, 2003-06).

Because IMT-Advanced wants to fulfil wireless communication needs for everyone everywhere, at speeds reaching 100 to 1000 Mbps, it is one of the most ambitious and potentially disruptive telecommunications projects ever conceived. It is certainly the largest source of pressure on currently allocated spectrum. Though based on highly efficient radio interfaces and network architectures, its spectrum needs are larger than we can yet estimate. It is hard to see how enough harmonized spectrum can be found during the next five years to enable the technology to reach its full potential, or how one – let alone three – nationwide IMT-Advanced networks could be squeezed into the preferred frequency range without displacing, imposing substantial costs or otherwise adversely affecting a very large number of incumbents.

It is important to recognize that the costs of infrastructure and spectrum were ignored in formulating the requirements of IMT-Advanced.[103] That may be useful as a way to imagine an ideal network or identify ultimate goals, but ignoring economics in the design can lead to an unrealizable project. Note, too, that the performance targets (1 Gbps data transfer speeds for the low-mobility scenario, 100 Mbps for the high-mobility scenario) are far in excess of the Digital Agenda's goals.

Figure 2.11. IMT-Advanced is not just a new cellular radio standard




Source: (ITU, 2003-06)

### 2.8.2 Spectrum and infrastructure costs for 4G

We estimate the cost of 1 GHz of cellular spectrum in the EU-27 countries at about €320 billion, based on the inflation-adjusted per-MHz price average of 200 previous cellular licence auctions.[104] Pricing the 4G infrastructure is more difficult, because much of it can be accomplished with upgrades to existing 2G and 3G cell sites. But Döttling, Mohr and

[103] Only "traffic demands and spectrum efficiency coefficients" were used to calculate the spectrum requirements, according to ITU, 2006b.

[104] A *PolicyTracker* study (Sims, 2011) of over 200 auctions of mobile licences since 2000 found the cost per MHz per capita trending downward, with the inflation-adjusted average price for new mobile spectrum equal to $1.01/MHz/pop, and an average of $0.90/MHz/pop for spectrum at 2 GHz. If we take the latter price as a rough indication of what 1 GHz of additional spectrum might cost for IMT-Advanced to serve 500 million people in the EU, the total is $450 billion (€320 billion).

Osseiran (2009) estimate the "green field" cost of dense urban 4G network infrastructure at about €84,200/km² and the cost of rural deployments at €4,350/km².[105] We averaged the urban and rural cases to create an "intermediate population density" network cost estimate of €44,275/km². Eurostat says the land area of the EU-27 is 9.1% urban, 34.9% intermediate and 56% rural, so we applied those figures to the total land area and then reduced rural coverage to 80%. On that basis we estimate the total deployment cost of base stations, relays and backhaul in the EU-27 with one complete IMT-Advanced network per country at €108.3 billion.

As noted, that can be reduced by recycling infrastructure from earlier generations of cellular technology – or by failing to recycle, simply leaving "holes" in the coverage. On the other hand, the ITU's 2007 underestimate of the capacity requirements could mean that more base stations will be needed. In any case, there is a close match between the model used by the ITU to calculate spectrum requirements and the network topology priced by Döttling, Mohr and Osseiran, so we believe the specific dimensions of spectrum and infrastructure cited here are in fact complementary. Therefore, summing them (€428.3 billion) should reasonably approximate the potential cost of equipping the EU-27 with "full" 4G network coverage. That does not include:

- the cost of refarming new spectrum bands
- the cost of operating the network. Opex over 10 years may be double the capex, depending on many factors (eg cell sites and backhaul) although savings from the re-use of existing cell sites should be expected.

However, this estimate is consistent with an open letter sent by the GSM Association to a meeting of the G20 in 2009. In that letter, 24 leaders of the mobile telecommunications industry said they plan to invest $800 billion in network expansion during the next 5 years and "$550 billion of this is earmarked for mobile broadband…".[106]

### 2.8.3 IMT-Advanced – the death of infrastructure competition?

But just as a smart phone is no longer only a phone, IMT-Advanced is no longer only cellular. It is a heterogeneous network of networks. One is tempted to add "like the internet", although there are fundamental differences, particularly in terms of the business model – or so we assume, since public discussions of business models for IMT-Advanced are still rare. The ITU speaks of "one-network" deployments, but they are "one network" in the sense that access networks can overlap, forming a continuous blanket of services, and end-users may be automatically transferred from one component network to another without requesting or being aware of the transfer. They might also not receive separate bills for service from each network. Yet many of the component networks (satellites, High Altitude Platforms, backhauls, hotspots, narrowband M2M, etc) could be separately owned and operated. Thus, co-operative arrangements among different legal entities are more likely to characterize IMT-Advanced than overall ownership by a single enterprise. That will allow great flexibility in structuring IMT-Advanced as a business, and probably lead to significant national differences in market structure. Nevertheless, extensive cooperation

[105] For a detailed discussion of the derivation of these infrastructure cost estimates, see Chapter 14, "Cost Assessment and Optimisation for WINNER Deployments" in Döttling, Mohr and Osseiran (2009). They assume cost-optimised configurations, a 10-year operating period and exclude the cost of MIMO, gateways and radio resource management equipment.

[106] The letter is reprinted in a Global Telecoms Business article, Mobile industry leaders tell G20 they can help put the economy on track (2 April 2009), http://www.globaltelecomsbusiness.com/Article.aspx?StoryID=719049

and shared infrastructure raise questions about the resulting limitation of competition.[107] A "one-network" solution which blurs the boundaries between fixed and mobile broadband – and between telecommunication and broadcasting – raises the spectre of national and trans-European monopoly networks.

Mobile telephony has not heretofore been subject to the same kind of scrutiny and intervention by regulators as fixed telephony because it has been taken for granted that competition in mobile markets is sufficient to discipline the service providers and provide consumers with genuinely distinct choices. That assumption may need to be re-examined if IMT-Advanced integrates a very large number of services and markets which had been separate. However the market is re-defined, IMT-Advanced networks are likely to have significant power, so as with fixed telephony, regulators may find it necessary to set rules for non-discriminatory access to core services, to require wholesale price transparency and standardized service offers and contracts, to restrict mergers between peers, ensure competition in the provision of core services, etc.[108] "The RSPG considers that it is essential for the Commission and Member States to keep supporting the development of competition and innovation for these services".[109]

For licensed spectrum – and the ITU clearly assumes spectrum for the new 4G radio interface will be licensed – regulators may need to consider the need for "structural separation". According to the OECD, "regulators are concerned that firms which control bottleneck infrastructure will seek to use this to their advantage relative to other firms. To overcome this problem, some countries… are introducing models that include vertical structural separation…".[110] That might mean operators from one IMT-Advanced layer – an owner of core services, for example – might not be allowed to have a wireless access network licence. From a regulatory perspective, the key questions must be:

> *Can the benefits of competition be maintained in an allocation enabling only one IMT-Advanced network per country? And, if so, how?*

Recent market studies suggest that cellular's average revenue per user (ARPU) is steadily falling in Europe and the costs of upgrading and expanding networks to accommodate future demand will exceed the anticipated revenue.[111] An economic downturn, with austerity being imposed on a growing number of countries to reduce government borrowing and budget deficits – a by-product of which is a reduction in the public's disposable income – could restrain spending on mobile services for many years.[112] Therefore, as Janette Stewart observed, "future spectrum estimation models might need to

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[107] Rasmussen, P. (2010) LTE network sharing could sideline smaller operators, FierceWireless Europe, 14 May, http://www.fiercewireless.com/europe/story/lte-network-sharing-could-sideline-smaller-operators/2010-05-14

[108] For an analysis of business arrangements designed to protect competition and transparency in the context of infrastructure sharing, see Gustafsson (2010).

[109] RSPG Working Group on Wireless Broadband – Final Position Paper (DG INFSO/B4/RSPG, 2009)

[110] Next generation broadband access and market structure, OECD Communications Outlook 2011, page 136, http://www.oecd.org/sti/telecom/outlook

[111] See, for example, Tellabs (2011).

[112] Parker, A. (2011), Europe's mobile operators feel the pressure, Financial Times, 9 June, http://www.ft.com/intl/cms/s/0/360e6cfe-92b8-11e0-bd88-00144feab49a.html: "…in the first three months of this year, revenue generated from mobile services in the top five European markets – France, Germany, Italy, Spain and the UK – fell by 1.7 per cent… and the results showed some operators' revenues falling sharply in southern Europe, where consumers in countries reeling from the sovereign debt crisis are cutting their mobile spending in response to austerity measures…"

be developed to forecast the spectrum required to meet only the traffic demand that can be economically delivered via mobile networks…".[113] Ignoring foreseeable constraints on supply and demand when formulating the needs of a major new service creates unfulfillable expectations and puts an unfair burden on neighbouring spectrum users who have learned to live within their constraints.

### 2.8.4 Licensed/exempt convergence – integration at the level of the handset

| Connections to AT&T's Wi-Fi Network[114] | |
|---|---|
| 2nd quarter 2008 | 3.7 million |
| 2nd quarter 2009 | 15.0 million |
| 2nd quarter 2010 | 68.1 million |
| 2nd quarter 2011 | 246.8 million |

The fact that offloads to Wi-Fi and other licence-exempt RLANs will still be needed to support the most technically advanced and efficient network that the cellular industry and the ITU can envision speaks louder than words. As fast as data demand is growing on cellular mobile networks, growth is twice as fast on a cellular operator's Wi-Fi network (see table at right) and 4-6 times as fast on Wi-Fi networks in general (see Figure 2.1).

Today's MNOs see Wi-Fi as a useful supplement to their service. Tomorrow it will be an essential component. The day after tomorrow it may be cellular which is considered a useful supplement to Wi-Fi.

The cellular industry once had a negative view of Wi-Fi, because of its small coverage areas, lack of hand-off capability and quality of service not guaranteed by a licence. But the popularity of internet access via smart phones, the high price of cellular data plans and the slower download speeds still typical of cellular has made the freedom to switch between cellular and Wi-Fi a must-have feature for high performance handsets. Global sales of cellular/Wi-Fi handsets have skyrocketed, from 36.8 million in 2007[115] to nearly 247 million in 2010.[116] IHS iSuppli anticipates that global sales in 2011 will more than double last year's total, reaching 512.8 million handsets.[117]

Yet even these large numbers pale in comparison to Bluetooth, a short-range standard for creating ad hoc "personal area networks" (PANs) in the 2.4 GHz band. The first cell phone with Bluetooth was introduced by Ericsson in 2000, so it is fair to say that Bluetooth paved the way for all the ancillary radio systems now found in mobile phones. Initially seen as a way to eliminate earphone wires or to connect a hands-free microphone, Bluetooth also supports data transfers between nearby devices – a personal computer, a

[113] Stewart, J. (2011) 3G and 4G spectrum requirements: a question of balance, Analysys Mason Insight (July), http://www.analysysmason.com/About-Us/News/Insight/Insight_spectrum_requirements_ Jul2011/

[114] Burns, C. (2011) AT&T infographic notes massive Wi-Fi use growth on mobile devices, SlashGear, http://www.slashgear.com/att-infographic-notes-massive-wi-fi-use-growth-on-mobile-devices-22167040/

[115] Wi-Fi Alliance (2009) Wi-Fi chipset sales grew 26 percent to 387 million in 2008, 8 January, http://www.wi-fi.org/news_articles.php?f=media_news&news_id=770

[116] In-Stat (2011), Business Wi-Fi/cellular phone shipments approached 247 million units in 2010, 26 May, http://www.instat.com/press.asp?ID=3146&sku=IN1105048CT

[117] Rebello, J. (2011) More than 1 billion devices to have embedded wireless networking capability, IHS iSuppli press release, 15 April, http://www.isuppli.com/Mobile-and-Wireless-Communications/News/Pages/More-Than-1-Billion-Devices-to-Have-Embedded-Wireless-Networking-Capability.aspx

camera, someone else's phone, a medical/health monitoring device, etc.[118] About 1.2 billion mobile handsets equipped with Bluetooth will be sold this year.[119]

Wi-Fi and Bluetooth are found in most mobile handsets now (often sharing a single microchip), and GSM's co-existence with different implementations of UMTS requires most handsets to incorporate at least 2 or 3 cellular transceivers. But it doesn't stop there: a growing number of handsets have additional radio interfaces:

- **Broadcast receivers** – According to Akamai, 30-40% of all mobile broadband data today is video. An additional 2-5% is online audio – internet radio stations and podcasts. (Belson, 2011) Crafting future networks for higher speeds invites even more audiovisual content, and indeed, a recent draft of an ITU report on trends in mobile applications predicts that video "will account for 66% of mobile data traffic by 2014". (The memo adds, however, that TV services offered by mobile network operators will be "rather insignificant"[120] compared to the quantity of videos transferred to and from the internet by end-users.)

  European countries began issuing licences for broadcasting to mobile handhelds in 2006, on channels allocated to television and DAB rather than on cellular frequencies. Setting aside the principle of technology neutrality, in 2008 the European Union endorsed "the open standard DVB-H – which has been developed by European industry, partly with the support of EU research funds – as the common standard for terrestrial Mobile TV across Europe".[121] Expectations were high ("Mobile TV could reach a market of up to €20 billion by 2011"), yet most of the services quickly failed. DVB-H survives now only in Italy, Spain, Poland and Russia, and most of these services are faltering, according to *Broadband TV News*.

  A few cellular handsets incorporate UHF TV tuners to catch local signals but these only proved popular in Japan and Korea.[122] However, a new round of mobile TV projects recently started, not based on DVB-H or dependent on a separate allocation of spectrum. Video streamed over LTE eliminates the need to build a new network, yet even with greatly reduced startup costs, the new projects might still be entering a *cul de sac*. Tablets are "quickly becoming the new TV", as one commentator put it.[123] Yet the public seems to want only Wi-Fi tablets.[124] Just one model on Amazon's list of the 20 best-selling tablets has 3G connectivity

[118] It is possible to connect to the internet using a handset's Bluetooth module, although this is not an optimal solution, using Bluevibe hotspot and client software, for example: http://www.bluevibe.net/

[119] Foley, M. (2011) Installed base of 4 billion products with Bluetooth technology, Bluetooth SIG, 22 July, http://www.bluetooth.com/MikesBlog/Lists/Posts/Post.aspx?ID=31

[120] ITU (2011), SWG IMT.UPDATE Annex 3: Detailed Information on Usage and Mobile Application Trends, Document 5D/TEMP/568-E (14 July), page 9.

[121] European Commission (2008), Mobile TV across Europe: Commission endorses addition of DVB-H to EU List of Official Standards, IP/08/451 (Brussels, 17 March) - http://europa.eu/rapid/pressReleases Action.do?reference= IP/08/451

[122] PDAlist keeps track of such devices, and currently shows 8 models, all introduced between 2003 and 2007, so some of them may no longer be available. See http://pdadb.net/index.php?m=pdalist&list=tv

[123] Deruvo, J. (2011) Tablets quickly becoming the new TV, Android Community, 10 April, http://androidcommunity.com/tablets-quickly-becoming-the-new-tv-20110410/

[124] Hamblen, M., 3G tablet sales 'very slow,' analyst says, Computer World, 11 July, http://www.computerworld.com/s/article/9218284/3G_tablet_sales_very_slow_analyst_says

– an Apple iPad with both 3G *and* Wi-Fi – but the iPad's Wi-Fi-only versions outsell it by a wide margin.[125] This must be a concern to cellular operators – though a relief, too, since the average tablet generates five times as much data traffic as a smart phone.[126] Unless sales of 3G-enabled tablets improve significantly, delivery of television via cellular networks may reach tablet owners (who are likely to be the primary audience for mobile TV) only if programmes are also available via Wi-Fi, and in that case, cellular distribution might be just a fallback option, accepted only where Wi-Fi is not available. If Wi-Fi becomes the primary medium for mobile video distribution, band saturation will accelerate.

iSuppli estimates that globally, about 600 million cell phones – 34% of the total – were bought with built-in FM radio receivers in 2011.[127] Since digital systems like DAB, DAB+, DMB and DRM+ were developed to replace FM, one may wonder why so many cell phones still come with FM instead of one or more of the digital successors. There are many reasons. Most important, there is no agreed date or plan for switching off FM broadcasting in Europe.[128] Many people see no reason to stop listening to FM – or to start listening to digital – until their favourite stations are switched off. But FM might *not* be switched off: no "digital dividend" awaits release in the 88-108 MHz band and listeners seem satisfied with FM's sound quality and coverage. Second, the current crop of one-chip digital audio receivers drain battery-power much faster than FM chips. Since the audience for digital audio broadcasts is still smaller than the audience for FM – and is fragmented by the broadcasters' use of a variety of incompatible standards – there are not yet enough regular listeners to any type of digital sound broadcasting to create significant demand for that capability in mobile phones. With low demand, high battery drain and multiple standards to support, handset makers generally shun digital audio broadcast reception altogether, prolonging FM's reign.

- **GPS receivers –** Cellular networks need to know where each subscriber's handset is so incoming calls can be routed through the closest cell site. Location awareness is also the basis for a growing number of smart phone applications. Especially popular are navigation aids and street maps with "you are here" markers updated in real time. According to Berg Insight, 295 million GPS-enabled handsets were sold in 2010, and that number could rise to 940 million by 2015. The combination of handset GPS with "time-card" functions and location mapping is likely to prove essential for managing an increasingly mobile telework-force. But noting the many radios and sensors already built into smart phones, as well as GPS's limitations (indoor reception is normally poor and often impossible), Berg speculates that "further performance increases will come from hybrid location technologies that fuse signal measurements from multiple satellite

[125] http://www.amazon.com/Best-Sellers-Electronics-Computer-Tablets/zgbs/electronics/1232597011

[126] According to Cisco (2011).

[127] NAB (2008) FM Radios in Cell Phones, Radio TechCheck, US National Association of Broadcasters, http://www.nab.org/xert/scitech/pdfs/rd062308.pdf

[128] "…there are no wide-spread plans or strategies for the introduction of digital broadcasting in Band II [87.5 – 108 MHz, and] no universal switch off date for analogue services in Band II can be considered." ECC Report 141: Future Possibilities for the Digitalisation of Band II (87.5-108 MHz), St. Petersburg, May 2010, http://www.erodocdb.dk/docs/doc98/official/pdf/ECCRep141.pdf

systems, cellular networks and WLAN, together with data from sensors such as accelerometers, gyroscopes and altimeters".[129]

- **Near-Field Communication (NFC)** is another wireless technology which may soon become common in mobile phones. NFC operates at a frequency of 13.56 MHz, but for magnetic induction, not for the emission of radio waves. So the range of NFC is quite limited – less than about 20 cm. Despite that fact, NFC has generated great excitement as a possible medium for paperless ticketing (admission to public transport, concerts, sports events, etc.) and for mobile banking (using a mobile phone to store credit and make payments simply by tapping or waving the phone near an appropriate sensor). A poll of attendees at last January's Mobile World Congress suggested that widespread adoption of NFC is at least 2 years away.[130] Nevertheless, Berg Insight foresees the sale of 400 million NFC-enabled mobile handsets in 2015. ABI Research predicts sales of 552 million mobile handsets in 2016.[131]

### 2.8.5 A future with more licence-exempt radio

This brief review of licence-exempt radios in handsets hints at some points which should be made explicit:

First, as noted earlier, we need to stop thinking of these devices as cell phones because they are already so much more. In the same way that large flat LCD/LED displays now have many inputs, so they are general purpose image presentation surfaces, not just televisions, our handsets are becoming general purpose nodes of connectivity, data capture, storage, processing, retrieval and display – less like telephones than microcomputers with multiple radio links.[132] In its reports on IMT-Advanced, the ITU speaks of mobile handsets as "portable personal internet access devices" – an inelegant phrase, to be sure, but one that seems accurate. They need a catchier name, to help us think about what they are becoming.[133]

Second, because portability means handsets are constrained in size, weight and power, yet the market for them is huge, they demand innovation and reward it generously, especially in regard to miniaturization and integration. It is not unusual for cell phones to have Bluetooth, Wi-Fi, an FM receiver and receivers for GPS and Galileo all integrated on one

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[129] Shipments of GPS-enabled GSM/WCDMA handsets grew 97 percent in 2010, Berg Insights, 19 April 2011, http://www.berginsight.com/News.aspx?m_m=6&s_m=1

[130] Mansfield, I. (2011) Widespread adoption of NFC payments at least two years away, Cellular News, 24 February, http://www.cellular-news.com/story/48052.php

[131] ABI Research (2011), Multiple Secure Elements Drive NFC Market above $1 Billion in 2016, http://www.abiresearch.com/press/3791-Multiple+Secure+Elements+Drive+NFC+Market+above+%241+Billion+in+2016

[132] As if to emphasize this, Samsung recently introduced an Android smart phone with no GSM/UMTS radio module. Solomon, K. (2011) Samsung Galaxy Wi-Fi 3.6 is a smart phone without the phone, TechRadar, 1 September, http://www.techradar.com/news/portable-devices/portable-media/samsung-galaxy-wi-fi-3-6-is-a-smartphone-without-the-phone-1008695

[133] "…within the next year or so, you can expect to see people mothballing their old cellphones in favor of new software-defined handsets. By 2015, the transition should be nearly complete… many people are waiting for the day when they'll carry just one handheld gadget they can instantly switch from cellphone mode to that of a satellite radio receiver, or from a wireless Web browser to a mobile TV set…." Koch, P. and Prasad, R. (2009) The Universal Handset, IEEE Spectrum (April), http://spectrum.ieee.org/computing/embedded-systems/the-universal-handset/

silicon substrate.[134] And because cellular technology is still evolving rapidly, software updates are preferable to physically replacing parts. Therefore, mobile handsets and base stations represent early commercializations of software defined radio (SDR) (Ralston and Bier, 1998).

Third, mobile network operators in the US have the right to control which handsets can be used on their networks, and what features those handsets may support. As a result, according to Tim Wu, "carriers have blocked, crippled, modified or made difficult to use, at one time or another" Wi-Fi, Bluetooth, GPS, email clients, internet browsers, and other features now standard on smart phones (Wu, 2007). The tide turned in 2007, when Apple introduced the iPhone (which initially could only be used on AT&T's network), Google organized the Open Handset Alliance, and Verizon voluntarily adopted an "Any Apps, Any Device" policy. But these were all choices made by firms powerful enough to go against industry norms. The general principle of subscribers having the right to use any handset not harmful to a cellular network is still not firmly established in the US – in contrast to Europe. Here, thanks to the R&TTE Directive, and the distinction between "terminal" and "telecommunications network" introduced in EU legislation in the 1990s, if the cellular interface conforms to CEPT standards and other radios in the handset do not impair that conformity, network operators cannot stop their subscribers from using any compatible handset to access the network.[135] Lack of this right in the USA shows how important it is for attaining maximum consumer benefit – and how important it will be to preserve in any update of the R&TTE Directive. Questions have been raised about the continuing relevance of the terminal/network distinction with regard to fostering competition.[136] But there can be no doubt that the distinction will be even more relevant if frequency- and infrastructure-sharing in IMT-Advanced makes competition between cellular networks more limited or superficial.

Mobile network operators see tighter integration between cellular and Wi-Fi as a way to reduce their risks and gain more benefits. So many paths to integration are being explored. These have ripened into a wide range of initiatives:

- The IEEE is working on extensions to the 802.11 WLAN standards to support roaming (802.11r) and "interworking with external networks" (802.11u will enable hotspots to query a network to check if a particular device should be allowed access).
- The Next Generation Hotspot Program aims to standardize user- and network-authentication processes based on IEEE 802.11, to enable seamless roaming from home- to carrier-provided Wi-Fi.[137]
- The Wi-Fi Alliance's Certified Hotspot Program will test products offering "streamlined access", user authentication, and other features needed for easy controlled hand-offs between cellular and Wi-Fi.[138]

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[134] MediaTek (2011) MediaTek announces world's smallest 4-in-1 combo chip Wi-Fi/Bluetooth/GPS/FM solution, http://www.mediatek.com/en/News/news_content.php?sn=82

[135] R&TTE Guide (2009), http://www.ero.dk/B8FF1CC0-8C6C-4C8C-9019-7EB21FCABBD6

[136] Report from the Commission to the Council and the European Parliament: Second progress report on the operation of Directive 1999/5/EC, on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity Brussels, 9.2.2010 COM(2010)43 final - http://circa.europa.eu/Public/irc/enterprise/tcam/library?l=/public_documents/tcam_29/2928_progress_rtte pdf/_EN_1.0_&a=d

[137] Wireless Broadband Alliance drives industry to Next Generation Hotspots, 16 June 2011, http://www.wballiance.com/images/news/pdf/wba_release_june_2011_fh_signoff_final.pdf

- The Wireless Broadband Association, the Wi-Fi Alliance and the GSM Association are collaborating in HotSpot 2.0 software trials.[139]
- In 2010, Sagem Orga and Telefonica introduced SIMFi, the first SIM card with an integrated Wi-Fi hotspot and router. A mobile phone without Wi-Fi can be retrofitted with SIMFi to deliver HSPA internet access to Wi-Fi equipped devices nearby.[140]
- Wi-Fi is now widely available in public transport – on trains and buses, even taxis and subway systems. The vehicle's connection to the internet is often through a cellular network.

Can the integration of cellular and licence-exempt radio lead to cellular networks operating in licence-exempt spectrum, or in a combination of licensed and licence-exempt spectrum? Carrier-owned hotspots prove that the latter situation already exists, and the ITU's work on IMT-Advanced shows that this combination is not just a temporary "patch".

But the former situation already exists, too. Florida-based xG Technology has developed a cellular system which apparently detects and avoids interference from other sources, enabling it to deliver noise-free "carrier grade" voice and data channels in licence-exempt bands using low-power base stations. The technology is "frequency agnostic" but the first two commercial "xMax" networks use the 902-928 MHz ISM band in Fort Lauderdale, Florida and Lewisville, Arkansas. Additional networks are planned in 8 more places in 2012.[141] The US Army bought two xMax networks to test against "deliberately induced interference" and is now evaluating their performance in "hostile electronic environments".[142] Development work has started on xMax base stations and handsets for the licence-exempt 5GHz band.

Note, too, that the 2010 update of the mobile WiMAX standard added new politeness protocols and interference mitigation techniques to improve WiMAX's co-existence with other systems in licence-exempt bands.[143] Since WirelessMAN-Advanced (the 2010 update

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[138] Wi-Fi Alliance (2011) Wi-Fi Certified™ Hotspot Program to Ease Subscriber Connectivity in Service Provider Wi-Fi Hotspots, 22 March 2011, http://www.wi-fi.org/news_articles.php?news_id=1048

[139] Dimitrov, D. (2011) Hotspots 2.0 – around the corner!, Compojoom, 1 July, http://compojoom.com/blog/news/hotspots-20-around-the-corner

[140] World premier: Sagem Orga and Telefonica turn the SIM card into a Wi-Fi hotspot, 12 February 2010, http://www.sagem-orga.com/index.php?myELEMENT=World%20premier:%20Sagem%20Orga%20and%20Telefonica%20turn%20the%20SIM%20card%20into%20a%20Wi-Fi%20hotspot

[141] Engebretson, J. (2011) "Eight small telcos ink deals to evaluate new broadband wireless technology", *Connected Planet*, 25 July, http://connectedplanetonline.com/independent/news/Eight-small-telcos-ink-deals-to-evaluate-new-broadband-wireless-technology-0725/. An overview of xMax technology and cost estimates for building and operating an xMax network are given in xG Technologies (2010) Stacking xMax® against WiMax™ IEEE 802.16e, http://xgtechnology.com/documents/Stacking%20xMax%20Against%20WiMax%20White%20 Paper_FINAL.pdf.

[142] Kenyon, H. (2011) "US Army begins field-testing xMax cognitive cellular system in licence-exempt 920MHz band", *Defense Systems*, 6 June, http://defensesystems.com/articles/2011/06/06/ cognitive-radio-begins-field-tests.aspx. xG Technologies (2011) xMax 'performs as advertised' in both laboratory evaluation and a six-month field trial with the United States Army, press release, 23 August, http://xgtechnology.com/2011-Press-Releases/xmax-performs-as-advertised-in-both-laboratory-evaluation-and-a-six-month-field-trial-with-the-united-states-army.html

[143] IEEE (2010) 802.16h - IEEE Standard for Local and metropolitan area networks, Part 16: Air interface for Broadband Wireless Access Systems, Amendment 2: Improved Co-existence Mechanisms for License-Exempt Operation, 30 July, http://standards.ieee.org/getieee802/ download/802.16h-2010.pdf

of WiMAX Mobile) is an approved 4G radio interface, IMT-Advanced has acquired tools to co-exist with other services in licence-exempt spectrum through WiMAX.

LTE-Advanced, on the other hand, was not designed for licence-exempt spectrum, but minor modifications enable it to work in that environment.[144] In February 2011 the Wireless Innovation Forum launched a TD-LTE White Space Project to analyse and report on the prospects of LTE networks using licence-exempt spectrum in the digital television band.[145] This project is led by an engineer who works for Huawei, which in October 2011 started field testing its own LTE white space network.[146]

The FP7-funded COGEU project examined the technical performance of LTE in UHF white spaces and described how such deployments might supplement network capacity requirements (Silva, 2011). Meanwhile, members of the FP7 QUASAR project presented a "business feasibility analysis" of mobile broadband provision in TV white spaces to a COST-TERRA meeting in Brussels last November, and perhaps not surprisingly, they found the business case to be much stronger than for fixed broadband access in rural areas.[147] Taking a different approach, Peng and his colleagues (2009) suggest moving femtocells into UHF white spaces so they do not compete with larger base stations using licensed frequencies.[148]

These small moves by Huawei, Ericsson, xG Technologies and others suggest the cellular industry's consensus that only licensed bands are acceptable for carrier-grade services may be weakening. The CEPT Electronic Communications Committee was prescient in recognizing that the development of technologies providing adequate quality of service without government-backed interference protection would enable the expansion of cellular networks into licence-exempt bands. In their 2002 strategic plan for the 2.4 GHz band they had written:

> the major operators most likely will avoid the use of unlicensed bands for public services as these bands will not allow them to provide QoS to their customers… [But should that change] the use of SRD-applications for public operated networks may dominate the spectrum in a given area and prevent especially the simplest SRD applications from using the band. It is underlined that Administrations have no legal means to prevent public

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[144] Rahman, M.I., et al., (2011) License-exempt LTE systems for secondary spectrum usage: Scenarios and first assessment, IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN-2011), http://ieeexplore.ieee.org/iel5/5910696/5936192/05936224.pdf. For a more general treatment of spectrum availability issues by members of the QUASAR FP7 project, see Koufos, K. *et al*. (2010) Feasibility of Voice Service in Cognitive Networks over the TV Spectrum, 5th International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom), http://www.quasarspectrum.eu/images/stories/ Documents/publications/CrownComAalto.pdf

[145] Wireless Innovation Forum (2011) Call for participation: TD-LTE White Space Project, announcement, February, http://www.wirelessinnovation.org/assets/documents/Project_TD-LTEWhite Space.pdf

[146] Huawei (2011) Huawei to Launch TV White Space LTE TDD System Trial, 20 October, http://www.huawei.com/en/about-huawei/newsroom/press-release/hw-103931-huaweitvwsltetdd.htm

[147] Markendahl, J. et al (2011), Business feasibility analysis of use of TV WS for mobile broadband services taking into account spectrum pricing, presented at the 4th COST-TERRA meeting, Brussels, http://www.cost-terra.org/uploads/TERRA%20web%20content%20files/November2011_meeting/WinnerIIplace_Markendahl.pdf

[148] Peng, F., et al. (2011) Using TV White Space for Interference Mitigation in LTE Femtocell Networks, IET International Conference on Communication Technology and Application (Beijing, China), http://conference.bupt.edu.cn/iccta2011/article_web/uploadArticles/225-20110729212841.pdf

> networks in unlicensed Short Range Device bands including the band 2400-2483.5 MHz.[149]

Some who have been promoting the use of licence-exempt wireless networks for many years welcome this prospect:

> [Cellular architecture allows] the reuse of spectrum over distance, improving spectral efficiency, and the fundamental scalability of cellular is central to its success. Unlicensed cellular systems can have all of these properties, plus the elimination of the requirement for expensive licensed spectrum… we believe that cognitive-radio-based cellular systems deployed in the unlicensed bands will be both popular and technologically- and service-competitive with licensed cellular services. These systems will be carrier-class with all required management and operational-support-services capabilities, and superior to licensed systems in price/performance and return on investment.[150]

Increasing spillover of cellular data from mobile systems operating in licensed spectrum is likely to drive up occupancy levels in the licence-exempt bands in the next few years, first at 2.4 GHz and then at 5 GHz. Accelerating growth in the number of smart phones and tablets, easier handoffs from cellular to Wi-Fi, the growing popularity online video, and video streamed over Wi-Fi, the increasing uptake of Voice-over-IP and slow growth in femtocell deployments which use cellular frequencies, all point to a rising tide of portable-device generated browser data, streaming videos and voice calls whose dimensions are difficult to grasp. If cellular mobile networks are unable to get sufficient new allocations of licensed spectrum to accommodate the surge in traffic generated by their subscribers, they may have no choice but to follow their users into the licence-exempt bands. Most handsets already have 2.4 GHz radios and a growing number have 5 GHz.[151] If this migration starts in the next few years, saturation of these bands could follow quickly.

## 2.9. The European market for wireless broadband and the impact on sharing

### 2.9.1 Demand for shared spectrum: licensed and licence exempt

The main source of pressure on spectrum allocations now is the bandwidth sought for IMT-Advanced. Because the venue where this is project is developing is the ITU, which is in a unique position to turn decisions into a binding treaty, this must be taken seriously – even though the market forecasts on which their original estimates were based are too conservative and the economic viability of the project at full scale is uncertain.

The 581.5 MHz of spectrum previously designated for GSM and UMTS is now available for IMT-Advanced, plus 392 MHz from WRC-07, and 200 MHz more (3600-3800 MHz) starting in 2012.[152] This adds up to 1173.5 MHz – almost reaching the requirement for a

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[149] ECC Report 11: Strategic Plans for the Future Use of the Frequency Bands 862-870 MHz and 2400-2483.5 MHz for Short Range Devices (Helsinki, May 2002), page 10, http://www.erodocdb.dk/docs/doc98/Official/Pdf/ECCRep011.pdf

[150] Mathias, C. (2010) Redefining cellular infrastructure: Cognitive Radio and unlicensed spectrum, Farpoint Group white paper FPG 2010-433.1, page 7, http://xgtechnology.com/images/stories/docs/redefining%20cellular%20infrastructure.pdf

[151] "Adoption of dual-band WiFi (2.4GHz/5GHz) in handsets is estimated to increase from approximately 25 percent of all handsets [sold] in 2011 to approximately 50 percent of all handsets [sold] in 2012, with increasing emphasis on the 5 GHz band for use in 3G/4G smartphones." Joosting, J.P. (2011) 5 GHz WiFi front end modules (FEMs) for handsets, smartphones and tablets", *EE Times Europe,* 15 March 2011 - http://electronics-eetimes.com/en/5-ghz-wifi-front-end-modules-fems-for-handsets-smartphones-and-tablets.html

[152] The 581.5 MHz designated for GSM and UMTS includes 880-915 MHz, 925-960 MHz, 1710-1785 MHz, 1805-1880 MHz, 1900-1980 MHz, 2010-2025 MHz, 2110-2170 MHz and 2483.5-2690 MHz. The

one-network deployment in a low-density market using the old market forecasts, and the RSPP's target of 1200 MHz "to support EU policy objectives"[153] – if the bands were fully cleared. But clearing has not been agreed in 792 MHz of that spectrum, and there is no reason to assume it will be. If IMT can find a way to exploit half of that shared spectrum – with ASA, for example – it will have about 800 MHz of usable bandwidth, with an additional 700 MHz still needed for a 3-network deployment in a high-user-density market.

However, the ITU graphic (Figure 2.10) showing the new forecast for data traffic as 4 times the maximum of the 2006 forecast suggests the already designated spectrum will be nowhere near enough, even for one nationwide network.

There is also the not-officially estimated need for spectrum to accommodate a growing "exaflood" of offloads into the 2.4 and 5 GHz bands, which we understand was predicted to reach 640-860 MHz by the year 2020, based on the 2006 forecasts. The spectrum needed to accommodate future overflow from cellular would have to be much higher now.

While considering these large bandwidths, it should be noted that there is a European procedure for seeking change in spectrum allocations. A quick look at the currently pending requests reveals that the pattern of near-term demand contrasts sharply with the demand visible on the horizon.

The process of changing an allocation starts either in CEPT or in ETSI, in one of the technical workgroups. If they get a proposal from industry or academia or see a need themselves, a System Reference Document (SRDoc) is drafted by ETSI describing the candidate system's radio characteristics, identifying any sharing or compatibility issues and proposing an operating band.

Currently there are 15 SRDocs in an early stage of development (ie between "work started" and "final approval"). Three of them would change licensed bands – although none require additional spectrum – and twelve are for licence-exempt short-range devices. About half of the latter contain requests for new allocations. Noting that one SRDoc may contain several requests, the current requests for more shared access spectrum are for:

- RFID tags in the 865-868 MHz and 915-921 MHz bands
- "non-specific SRDs" in the 870-873 MHz band for building automation, wireless alarms, meter reading, etc.
- automotive applications in the 873-876 MHz band (eg keyless entry and tire pressure monitoring)
- Medical Body Area Network Systems (MBANS) in the 2360-2400 MHz band
- Low Power Active Medical Implants (LP-AMI) for outdoor operation in the 2483.5-2500 MHz band
- radar sensors in non-automotive surveillance applications in the 76-77 GHz band
- UWB location tracking devices in the railroad environment
- factory/industrial UWB applications

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392 MHz identified by WRC-07 includes 450-470 MHz, 790-862 MHz, 2300-2400 MHz and 3400-3600 MHz.

[153] The European Council's Common Position on the multi-annual Radio Spectrum Policy Programme, press release, 3134th Council meeting (Brussels, 12 and 13 December 2011), http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/other_docs/rspp/rspp_council_press_release_201112.pdf

The pattern is clear: while accommodating the growth of mobile broadband looms on the horizon as the largest pending problem, most current SRDocs relate to short-range devices supporting practical "niche" applications. Most of the requests are either for small slices of spectrum – just a few MHz – or for ultra-wide band (UWB) "underlays". New spectrum requests for SRDs also tend to be adjacent or near to existing SRD bands.

The SRDoc procedure is relatively slow, with the average application taking 6-12 months to process. However, caution is appropriate to the framework of traditional spectrum management where regulators are responsible for dealing with any interference complaints which arise. The "flexible use" regime which the Commission has been promoting should eventually reduce the number of situations requiring SRDoc procedures and speed up the processing of those which remain, as user responsibility for resolving interference issues increases. Much depends on the pace at which ETSI can adapt European radio interface standards to more flexible use, as discussed in the next chapter.

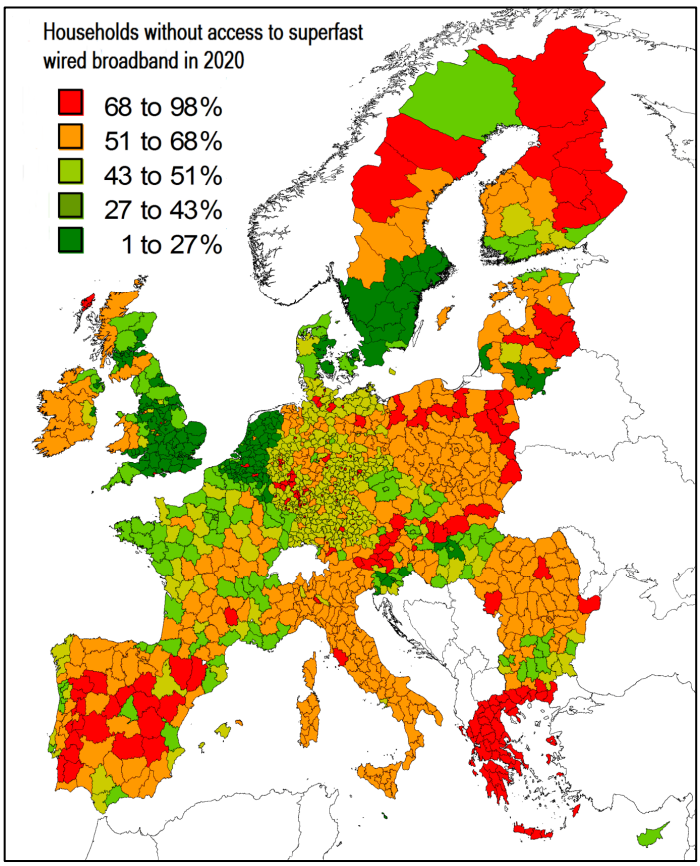
### 2.9.2 The wireless broadband and wireline options

Broadband access can be supplied either by wire or wirelessly. "Wire" here means optical fibres, co-axial broadband, twisted pair phone lines, leased lines, Ethernet, powerline communications and cable TV networks. Our focus is on the radio spectrum, however, so we will not discuss wired broadband, except to note a few basic facts:

- Wired and wireless networks are mutually substitutable in many situations. The use of wired connections obviously conserves spectrum but often requires a greater investment in infrastructure than deploying a wireless link.
- Hybrid networks, combining a point-to-point wired infrastructure with short-range wireless access zones for end-users, bring together the special advantages of each media type. They are often the most effective solution for non-local linkage and regulators should not make them harder to deploy simply because of the way regulatory agencies are organized, with wired media and wireless handled by separate departments.
- Wired broadband connections become much more costly per-subscriber as population density decreases, because installation and maintenance costs depend directly on the length of the wire-run. A study for l'Association des Régions de France found that the per house roll-out cost of optical fibre in the most sparsely populated areas of France is 18 times the per house cost in urban areas (AVICCA, 2011).
- A consequence of this last point is that about 23.5 million people in Europe have no access to wired or mobile broadband, including 18 million living in rural areas (Digital Agenda Scoreboard, 2011). Thus even though the markets for fixed wireless access (and satellite broadband) are currently small compared to wired broadband and cellular mobile, their social significance is large, in that they represent people who live and work outside the range of 3G mobile and DSL. Fixed wireless broadband for isolated areas might not add much to Europe's GDP, but it can make a decisive contribution to digital inclusion and social integration. And for the millions of people in such regions, shared access spectrum could make the difference between economically viable net connectivity and no connectivity at all.

The red and orange areas of Figure 2.12 show where this difference matters.

Figure 2.12. Households without access to superfast wired broadband in 2020




Source: Point Topic (2011)

### 2.9.3 The demand for wireless broadband – Wi-Fi and terrestrial mobile

Wi-Fi is the medium of choice for access to wireless broadband. According to Cisco's Visual Networking Index, in Europe the amount of internet data transmitted by Wi-Fi networks surpassed the amount of data transmitted by wire for the first time in 2011 (see Figure 2.1 and Table 2.4). In the wireless domain, 21.5 times as much internet data passed through Wi-Fi networks as passed through all the cellular networks in Europe (Cisco, 2011). So it is safe to say that the overwhelming majority of socioeconomic benefits from wireless broadband come via Wi-Fi and thus via shared access spectrum.

There are two fundamentally different economic models for wireless access – free v paid – and this affects the compilation of statistics. Consequently, we must be careful to distinguish between wireless broadband *subscribers* and wireless broadband *users*. The vastly larger amount of Wi-Fi traffic compared to cellular suggests that far fewer Europeans obtain wireless broadband access by paid subscription than by free access at home, work and hotspots. This has implications for the user-owned infrastructure model discussed in Chapter 3, and it provides an essential counterbalance to the OECD statistics shown in Table 2.5.

Table 2.4. Internet data traffic forecast by region and medium

| (Exabyte =10**18) | 2010 Exabytes/ month | 2011 Exabytes/ month | 2012 Exabytes/ month | 2013 Exabytes/ month | 2014 Exabytes/ month | 2015 Exabytes/ month |
|---|---|---|---|---|---|---|
| **Europe as a whole (including Russia)** | | | | | | |
| **Wi-Fi** | 2.53 | 3.66 | 5.19 | 7.11 | 9.51 | 12.25 |
| **Mobile** | 0.07 | 0.17 | 0.38 | 0.74 | 1.27 | 1.98 |
| **Wired** | 2.88 | 3.67 | 4.66 | 5.88 | 7.10 | 8.34 |
| **Central & Eastern Europe (including Russia)** | | | | | | |
| **Wi-Fi** | 0.26 | 0.43 | 0.67 | 1.01 | 1.47 | 2.10 |
| **Mobile** | 0.01 | 0.02 | 0.06 | 0.11 | 0.20 | 0.35 |
| **Wired** | 0.44 | 0.55 | 0.68 | 0.84 | 1.03 | 1.27 |
| **Western Europe** | | | | | | |
| **Wi-Fi** | 2.27 | 3.23 | 4.52 | 6.10 | 8.05 | 10.15 |
| **Mobile** | 0.06 | 0.15 | 0.33 | 0.63 | 1.07 | 1.63 |
| **Wired** | 2.44 | 3.12 | 3.97 | 5.04 | 6.07 | 7.08 |
| **Global** | | | | | | |
| **Wi-Fi** | 7.25 | 10.87 | 15.31 | 20.87 | 27.96 | 37.18 |
| **Mobile** | 0.24 | 0.55 | 1.16 | 2.20 | 3.81 | 6.25 |
| **Wired** | 12.70 | 16.63 | 21.14 | 26.36 | 31.52 | 37.02 |

Source: Cisco Visual Networking Index (June 2011).

The OECD has compiled data on the number of wireless broadband *subscribers* in 24 European countries, including non-EU members Iceland, Norway and Switzerland: 99.1% of the subscriptions are to the data services of cellular mobile networks. Satellites serve just 0.3% of the wireless broadband subscribers and terrestrial fixed systems serve about 0.6%.[154] The overall total number of wireless broadband subscriptions in the European countries surveyed by the OECD was 169,704,057. In Table 2.5, individual country totals are shown as of December 2010 (OECD, 2011). The Scandinavian countries stand out as the region with the highest penetration of wireless broadband subscriptions.

[154] OECD Broadband Portal, http://www.oecd.org/document/54/0,3746,en_2649_34225_38690102_1_1_1_1,00.html

Table 2.5. Wireless broadband subscription penetration, 2010

| Country | Population | Wireless broadband subscribers | (%) | Country | Population | Wireless broadband subscribers | (%) |
|---|---|---|---|---|---|---|---|
| Austria | 8,414,638 | 1,741,246 | 20.7 | Italy | 60,418,711 | 23,222,260 | 38.4 |
| Belgium | 11,007,020 | 1,104,752 | 10.0 | Luxembourg | 472,569 | 253,713 | 53.7 |
| Czech Republic | 10,535,811 | 1,257,400 | 11.9 | Netherlands | 16,696,700 | 6,315,000 | 37.8 |
| Denmark | 5,568,854 | 3,489,080 | 62.7 | Norway | 4,930,116 | 3,906,588 | 79.2 |
| Estonia | 1,315,681 | 268,700 | 20.4 | Poland | 38,192,000 | 19,997,607 | 52.4 |
| Finland | 5,357,537 | 4,549,000 | 84.9 | Portugal | 10,607,995 | 6,789,566 | 64.0 |
| France | 65,447,374 | 22,474,000 | 34.3 | Slovak Republic | 5,422,366 | 1,694,532 | 31.3 |
| Germany | 81,757,600 | 21,272,150 | 26.0 | Slovenia | 2,012,917 | 658,338 | 32.7 |
| Greece | 11,645,343 | 2,788,778 | 23.9 | Spain | 47,150,800 | 12,826,088 | 27.2 |
| Hungary | 9,979,000 | 879,061 | 8.8 | Sweden | 9,360,113 | 7,779,000 | 83.1 |
| Iceland | 304,261 | 147,314 | 48.4 | Switzerland | 7,785,000 | 3,647,850 | 46.9 |
| Ireland | 4,434,925 | 2,105,739 | 47.4 | UK | 62,041,708 | 22,642,034 | 36.5 |

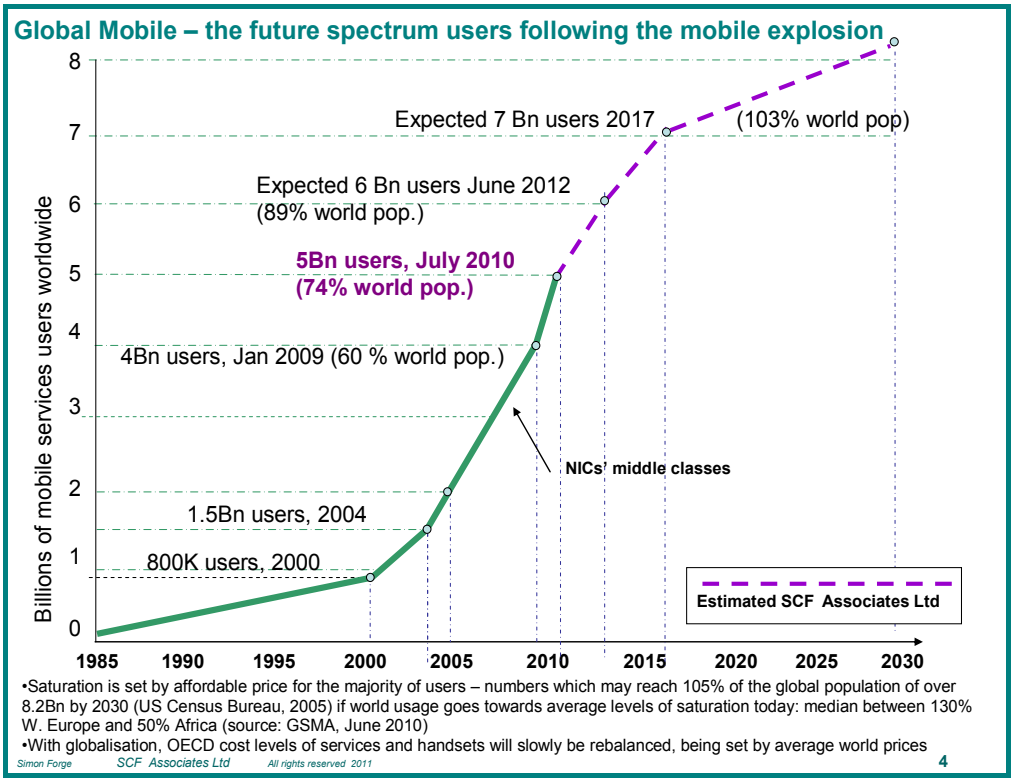
Europe's Digital Agenda Scoreboard says the penetration rate for mobile subscriptions in the EU reached 124.2% in October 2010.[155] Our forward projection, shown in Figure 2.13, asserts that we are passing through the inflection point now, where the rate of growth in mobile subscriptions (voice and data) is slowing even though the total continues rising. Further increase in the penetration rate is possible, as machine-to-machine communication develops. But it is not likely to be as significant during the next five years as the growth in network utilization by subscribers upgrading their access device from 2G to 3G to 4G, or from feature phone to smart phone to tablet.

As smart phones and tablets become the new norm, the mix of media content passing through cellular mobile networks changes. That is starting to affect network architecture and spectrum demand. The need for higher data transfer rates in individual connections favours higher frequency bands as well as densification of the network, and this combination multiplies the backhaul capacity requirement. We discuss this in the context of fixed point-to-point networks, below.

Because cellular networks are expensive, and because data revenue is growing more slowly than the cost of accommodating the growth in data demand, it is inevitable that cellular networks will turn increasingly to Wi-Fi and other RLANs as an alternative to traditional base station hardware. Sooner or later, and despite their ingrained preference for licensed spectrum, we believe the MNOs will recognize and support the need for more licence-exempt spectrum to satisfy their customers, particularly in bands identified for broadband. The complex partnership between cellular and Wi-Fi is explored in Chapter 2.7.

[155] http://ec.europa.eu/information_society/digital-agenda/scoreboard/docs/pillar/broadband.pdf

Figure 2.13. Global demand for mobile radio technologies




### 2.9.4 The wireless broadband market by bearer type – and the impact on shared spectrum

In addition to Wi-Fi and cellular mobile, the wireless broadband market consists of various types of communications distinguished by the type of bearer. In Europe, this market currently consists of five other segments, some of which implement shared infrastructure or frequencies:

- ***Fixed Satellite***: The Satellite Industry Association says consumers globally spent $1.1 billion for satellite broadband services in 2010, a 10% increase from 2009. (SIA, 2011) However, IDATE's estimate for *European* spending on satellite broadband in 2010 was just €47 million. At the end of 2008, IDATE noted 134,777 satellite broadband subscribers in the EU-27 plus Norway and Iceland. IDATE expects the European and North African satellite broadband market to reach 800,000 subscribers by 2015, if a 34% growth rate is achieved.[156] This growth-spurt can be attributed to a new "High-Density Fixed Satellite Service" (HDFSS), allocations for which were recommended at WRC-03. HDFSS describes satellites whose antennas form narrow beams for multiple simultaneous two-way broadband links direct to end-users. After WRC-03 CEPT approved 1,640 MHz of bandwidth for HDFSS downlinks and 760 MHz for uplinks[157] (ECC, 2005). IDATE's forecast of 800,000 subscribers, even though 23.5

[156] Maxime Baudry, Broadband satellite now a reality worldwide, IDATE blog, 1 June 2011 - http://blog.idate.fr/?p=742; de Selding, Ka-Sat enters service as European broadband market heats up, SpaceNews, 31 May 2011, http://www.spacenews.com/satellite_telecom/110531-ka-sat-enters-service.html

[157] The downlinks are at 17.3-17.7, 19.7-20.2, 47.5-47.9, 48.2-48.54 and 49.44-50.2 GHz; the uplinks are at 29.50-30 GHz.

million Europeans are currently beyond the reach of fixed terrestrial broadband networks suggests that many people won't find satellite broadband attractive even if the price is right, mainly because of the delay caused by sending data up to geostationary orbit where it is relayed back to Earth.

- ***Mobile Satellite***: MSS systems are usually configured as "constellations" of satellites - either positioned in geostationary orbit (like INMARSAT) or else with large numbers of small satellites moving across the sky in low- or medium-altitude orbits (LEO or MEO systems) such as Teledesic for broadband or Iridium for voice and data. The cost (up to US$3/minute for Iridium) and complexity of these systems has limited take-up of MSS services by the ordinary public. As a result, MSS has mainly served niche markets. Future growth is seen for MSS in supporting fishing fleets, offshore oil drilling and activities in the Arctic region. However, a study from TMF Associates reports a "dramatic deceleration in MSS revenue growth" in 2011[158]. Nevertheless, at WRC-07 14 MHz was allocated for mobile satellite support to IMT-Advanced. This was in addition to the 1626.5-1660 MHz band allocated for MSS and identified for IMT earlier. It remains to be seen if MSS for IMT will attract paying customers.

  In 2008, the European Parliament and Council established a procedure for the introduction of MSS in the 1980-2010 MHz and 2170-2200 MHz bands,[159] expecting high-speed internet access, mobile TV, emergency services, etc, in underserved and isolated areas. Inmarsat Ventures and Solaris Mobile were given two years to launch their satellites and then 18 years to operate them. But the EU does not have authority to licence the services' terrestrial elements – that is for the member states, and only a few responded, blocking service startup. In February 2011, the Commission issued an appeal to 21 Member States to finish authorising the ground support stations and in October 2011, Vice President Kroes added pressure to enforce the deadline: "Either operators deliver on their promises, or the spectrum which they have available… should be used in other ways".[160]

- ***Terrestrial Fixed Point-to-Point***: Until about 20 years ago, point-to-point networks mainly supported fixed telephony and broadcasting.[161] Between 1997 and 2010, the number of fixed microwave links in Europe increased from 156,657 to 363,842, a compound annual growth rate of 24.5%. The fastest growth occurred in the 38 GHz band (11,290 to 93,241 links) and the 23 GHz band (15,753 to 72,854 links) due to the improving price/performance ratio of the high frequency radio equipment. Most of the demand for new microwave links came from the expansion of cellular mobile networks. Point-to-point microwave provides about 56% of base station backhaul in Europe (Pigg, 2010). In France, 80% of the fixed service's total link capacity is used by mobile phone networks. While the links for wired telephony and broadcasting were mainly inter-city, the links for mobile network backhaul are mainly in-city. Therefore,

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[158] TMF Associates (2011), Not very happy holidays for the MSS sector, 29 November, http://tmfassociates.com/blog/2011/11/29/not-very-happy-holidays-for-the-mss-sector/

[159] Commission Decision of 14 February 2007 on the harmonised use of radio spectrum in the 2 GHz frequency bands for the implementation of systems providing mobile satellite services, http://www.erodocdb.dk/Docs/doc98/official/pdf/200798EC.PDF European Parliament and the Council Decision 626/2008/EC on the selection and authorisation of systems providing mobile satellite services (MSS), http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:172:0015:0024:EN:PDF

[160] Digital Agenda: Commission pushes for effective deployment of pan-European mobile satellite services, press release IP/11/1167, 10 October 2011, http://europa.eu/rapid/pressReleasesAction.do? reference=IP/11/1167

[161] Unless otherwise indicated, all facts and assertions in this section are based on Draft ECC Report 173: Fixed Service in Europe – Current Use and Future Trends post 2011

they are much shorter, allowing higher frequencies to be used. *Mobile Europe* reports that licence-exempt 60 GHz links are in great demand from cellular networks now as they offer huge bandwidth over very limited distances. By 2015 Infonetics expects that 70% of millimetre wave equipment will be deployed for backhaul.[162]

One of the distinctive features of the Fixed Service is that it has allocations in many frequency ranges, with many different authorization regimes: individual site licences, network block licences, light licensing with self-coordination and licence exempt. Most of the older fixed bands are at lower frequencies, shared now with mobile and point-to-multipoint networks. These are increasing in number, crowding out the fixed networks, particularly at 3400-3800 MHz, which has been identified for IMT and is widely used by WiMAX.

Point-to-point microwave links contribute significantly to the value of many other networks as infrastructure. But they are too costly for individuals to use as internet connections.

- ***Terrestrial Fixed Point-to-Multipoint***: This market segment is dominated now by WiMAX, the trade name for "products based upon the harmonized IEEE 802.16/ETSI HiperMAN standard".[163] Before the first WiMAX standard was released in 2001, all fixed microwave equipment was proprietary and non-interoperable. The aim of the WiMAX project was to change that by combining all the best signalling techniques in one open standard. WiMAX is discussed above in and around Box 2.1. We will not repeat that content here. However, WiMAX is also deployed in many countries as infrastructure for the commercial Internet access services described next.

- ***Terrestrial Fixed Point-to-Multipoint (licence-exempt)***: Because the next chapter discusses "user-owned infrastructure" and not-for-profit community networks, the focus here will be on wireless internet service providers (WISPs) using licence-exempt technologies – Wi-Fi and 5 GHz WAS/RLANs – to deliver internet access to people in their homes and offices on a subscription basis. These systems supply internet access to subscribers in Poland, Slovakia, Estonia, Latvia, Lithuania, Spain, Italy, Denmark, the Czech Republic, Serbia, the UK and elsewhere. Eastern Europe has disproportionate representation on this list because of the poor quality of the inherited telephone networks: bypassing them was the only way to connect to the internet, particularly in villages. IDATE (2009) estimates that up to 1.5 million people in Poland buy Internet access from commercial WISPs, with the Czech Republic and Italy next in market size.

  The ready availability of low-cost equipment for outdoor installations – as well as exemption from licensing – make market entry easy. The decreasing reliability of the 2.4 GHz band is one reason why 5 GHz is getting more popular with WISPS. Another reason is RouterBoard, made by MikroTik in Latvia. A complete 5 GHz RouterBoard base station costs a few hundred Euros, so starting a wireless internet access business is possible for almost any technically-minded person. Estonia, for example, with a total population of 1.35 mllion, has about a hundred WISPs in rural areas and small towns. Most of these businesses were started by young people who put a Routerboard transceiver on a church steeple, water tank or cell tower to cover

[162] Small Cell Backhaul, Mobile Europe, October/November 2011, page 25, http://viewer.zmags.com/publication/7f0b92ac#/7f0b92ac/24

[163] The WiMAX Forum FAQ, http://www.wimaxforum.org/resources/frequently-asked-questions/wimax-forum-faq

their neighbourhood. With a signal range of 10-15 km in a flat landscape, they can easily attract a thousand subscribers and make a nice profit (Horvitz, 2008).

Most WISPs are SMEs bringing internet access to areas poorly served by DSL. Unfortunately, they are often ignored or marginalized in national broadband plans, even when their services are the most affordable.

## 2.10. Spectrum needs arising from FP7-funded research projects

It is also indispensable in a study of this type to closely monitor the leading edge of radio technology research, to attempt to discern its directions and thus future demands from the market, when those products, business concepts and services now in their research phase come to market. Therefore as a key part of this study, we surveyed 118 projects funded under the 7th Framework Programme (FP7) of the European Community.

€8.2 billion has been earmarked for Information and Communication Technologies research during the 2007-2013 period. We tried to identify all of the projects whose results might affect future radio use – by, for example, creating new applications, improving efficiency or compatibility, developing new strategies for spectrum management, new band sharing or interference management techniques, etc. Projects were picked on the basis of their self-descriptions in the CORDIS database and on their websites.

Not surprisingly, most turned out to be members of FP7's Radio Access and Spectrum (RAS) Cluster. A complete list of the surveyed projects is given in Appendix B, with links to their websites. Early in the development of FP7's research agenda for radio, a meeting was held to discuss "Future Mobile and Wireless Radio Systems: Challenges in European Research". Drawing on information theory as much as on laboratory findings and the perspectives of leading researchers, an agenda emerged around a few fundamental questions:

- How to deal with interference?
- How to use multiple antennas?
- What is the optimal use of relays in wireless networks?

More practical questions then shaped the selection of specific projects for funding:

- What are the fundamental limits of wireless communication networks? What happens when they get very large and complex or operate in noisy environments?
- How can signals be separated?
- How can real-time measurements of channel conditions be used to improve the reliability of information transmission?
- How to increase spectrum efficiency, coexistence capabilities and throughput?

A unified fabric of research themes led to the selection of projects targeting significant problems, large and small. We developed a short questionnaire for them and 44 projects responded. Note that many of the non-responding teams had in fact disbanded after their research grant ended, leaving no one in charge of answering inquiries like ours.

Except for the following, all of the responding projects answered "no" to this question:

*"Is any change in radio spectrum allocation needed to implement the technology developed by your project?"*

Three-quarters of the respondents said their technology could be implemented with no changes in regulation. The exceptions were:

- COGEU and SACRA both said cognitive use of TV white spaces would have to be authorized for their technology to be implemented.
- ARAGORN needs the authorization of opportunistic sharing between primary and secondary networks, as discussed in the context of ASA/LSA.
- VISION called for faster regional harmonization of the rules regarding licence-exempt use of the 60 GHz band.[164]
- iPHOS called for "bandwidths of up to 30 GHz to be allowed on carrier wave frequencies in the licence-exempt spectrum" around 120 GHz.
- AMIMOS said that the way "equivalent isotropic radiated power" (EIRP) is regulated needs to adapt to and support the spreading use of MIMO techniques.
- For the CHOSen project, only a minor modification is needed: low-power wireless sensor networks for aeronautic applications should be permitted to use aeronautical frequencies.
- UCELLs is developing "a Cellular–UWB architecture" that uses ultra-wide band to create high-speed short-range picocells. They said raising the power limit for UWB transmissions is not mandatory but "the social impact of the project would be largely increased if PSD [power spectral density] in the higher frequency UWB bands" was increased.
- SAPHYRE, meanwhile, calls for a fundamental reorientation of radio regulation: "In contrast to the current definition of static licensed and licence-exempt spectrum, the SAPHYRE vision advertises dynamic spectrum sharing based on the context (congestion, QoS requirements, and channel conditions)."
- COST-TERRA is developing tools for "advanced coexistence modelling" and "rethinking current coexistence criteria." Some of their ideas inform our proposals in Chapters 3 and 5.

To sum up, our survey found that current radio regulations will not seriously impede the introduction of new wireless technologies generated by FP7 research projects. Many projects are working on aspects of dynamic spectrum access and cognitive radio. These are techniques which, if implemented, could change the way we regulate and use radio, starting as early as next year, when the Member States take up the question of whether to open UHF "white spaces" to opportunistic sharing. In terms of identifying technical usage conditions which need to be changed to implement innovative sharing techniques emerging from FP7 research, approval of the opportunistic use of "white spaces" by national regulators tops the list.[165]

Plus, a number of projects recognize a common pattern emerging from their work. It has come into focus as a need to migrate from rigid/static to flexible/dynamic spectrum authorization. This is our main conclusion as well.

[164] Radio frequencies around 60 GHz are strongly absorbed by oxygen in the atmosphere. Initially it was thought this would make wireless communication at 60 GHz impossible, but short-range links are still possible, and the high atmospheric absorption means frequencies can be re-used at very close distances, making this band ideal for extremely fast "hotspot" connectivity.

[165] Unfortunately, as noted elsewhere in this study, our survey of national regulatory authorities indicates that only 7 of them plan to authorize WSDs in the near future; 3 more are undecided..

# CHAPTER 3. Improving spectrum utilization through shared access

In this chapter, we provide some guidance for the development of responses to the problems and issues explored in Chapter 2. We examine the way forward by considering measures to raise the current low levels of radio spectrum utilization by improving opportunities for spectrum sharing. Growing demand for spectrum access to support an expanding range of socially and economically beneficial applications makes these measures necessary.

## 3.1. Changing technical conditions to enhance shared access spectrum

As noted in Chapter 2, band sharing is already extensive. Unshared allocations constitute just 0.8% of the European common allocations table (about 2.3 GHz out of 275 GHz), including 335.2 MHz (11.2%) of the spectrum below 3 GHz. Most of the exclusive bands are used by radar systems (76.8%), primarily military, and mainly above 15 GHz. Sharing between radio communication services and at least some of these radars seems feasible, under certain conditions, and could be expanded over time. Many radar allocations originated when efficient use of spectrum was not as essential as it is today, and earlier estimates of the systems' spectrum requirements were based on less advanced technology than exists now. The possibilities are explored in Section 3.3.

However, the extent of the gain from increased sharing would almost certainly depend on the existence of incentives for the incumbents to upgrade to systems more efficient in exploiting radio resources and more tolerant of shared frequency use.

At least part of the incentive for sharing might come in the form of "spectrum sublet fees" which the incumbents could keep as inputs to their budget. The Authorised Shared Access (ASA) and Licensed Shared Access (LSA) concepts, discussed below, could provide a suitable framework. The advantage of spectrum sublet fees as an incentive is that they increase with the number and economic significance of new band entrants.

However, given that the total amount of spectrum in exclusive allocations is limited, and most of it is above 15 GHz, improvements in spectrum utilization may be easier to achieve in bands with more desirable physical characteristics which are already shared but not intensively. As noted above, the problem of low spectrum utilization is not due to exclusive allocations so much as to exclusive channel assignments. This study found that the root causes are:

- rules for using spectrum tend to be rigid and persistent while most of our needs for spectrum access are dynamic and sporadic, and
- some regulators see their main responsibility as preventing interference to licensees rather than maximizing the benefits to society of spectrum use.

As a result, radio resources (infrastructure as well as frequencies) lie fallow much of the time so as to be available when needed – but only to the assigned user. Increasing the number of shared allocations would gain very little as long as channel assignments remain static, licences mainly go to systems dedicated full-time to a single purpose, and while it takes years to change the services authorized to use each band. So our consideration of potential changes in the technical conditions of spectrum use must encompass authorizations and licensing, interference management and flexible use. But our focus must be on ways to unlock the potential of channel sharing.

### 3.1.1 Modifying the aim of sharing/compatibility studies

As explained in Chapter 2, the traditional approach to band sharing begins with sharing and compatibility studies designed to determine the conditions under which two different systems can co-exist. The answers are generally static rules, such as emission masks, power limits that do not change over time, geographic exclusion zones, antenna height restrictions, etc.

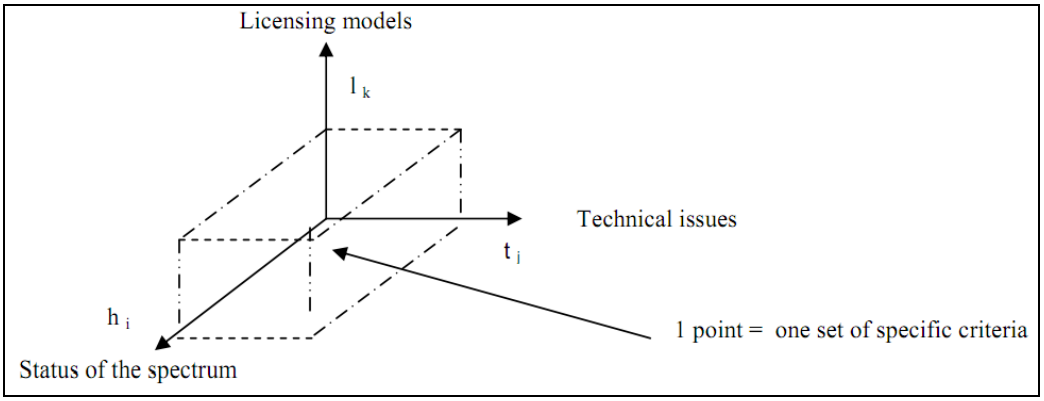
Nevertheless, there has been a gradual strengthening of the Commission's commitment to the principles of flexible use, technology- and service-neutrality, general rather than individual authorizations and the least restrictive technical conditions. These policy positions change the context in which compatibility and sharing studies are made. They imply more leniency in the technical conditions attached to authorization, and less specificity in radio interface standards. Given that the Commission has been promoting these policies for at least 5 years, one would expect changes in ETSI's drafting of harmonized standards to be visible by now.

The effect of flexible use policies on their work was the subject of an ETSI Report in 2008.[166] At the time they were only able to identify a few benchmarks to determine if they are adapting to the new policies:

- Do their standards allow for innovation and the inclusion of new technologies?
- Do the requirements affect both transmitters and receivers?
- Are the standards compatible with the R&TTE Directive?

A glimmer of hope that change might be coming is shown in Figure 3.1.

Figure 3.1. Three dimensional graph of criteria describing a spectrum use scenario




Source: ETSI TR 102 748 (2008-05)

[166] ETSI TR 102 748 V1.1.1 (2008-05) Technical Report: Impact of the trend towards flexibility in spectrum usage on the principles for drafting Harmonized Standards and the ETSI work programme for Harmonized Standards, http://www.etsi.org/deliver/etsi_tr/102700_102799/102748/01.01.01_60/tr_102748v010101p.pdf

Previously, ETSI used technical issues, spectrum status and a licensing model to define a unique set of criteria for spectrum use. Each combination of criteria is represented by a single point in 3-dimensional space. Under the new conditions of flexible use, the criteria for spectrum use should be "several sets of points". Yet ETSI spoke of that as "a later stage" of evolution, indicating that they still have a "one-point" perspective. However, at least they have conceptualized the problem. One of their suggestions for stimulating change was to use the European common allocations table to reveal the assumptions used in their compatibility/sharing studies. Perhaps the next step will be to change those assumptions.

Meanwhile, a potentially significant development is ETSI's drafting of a technical report[167] that could lead to the definition of a dynamic equipment authorization procedure for "reconfigurable radio systems" (cognitive radios, software defined radios). The procedure would be compatible with the new version of the R&TTE Directive, currently in preparation, and it would link equipment flexibility to the "essential requirements" of the relevant frequency band. Unfortunately, no draft text has yet been made public.

As indicated in the previous chapter, we would hope to see sharing studies recognize the possibility of active adaptation and accommodation between two or more band sharers, including negotiated levels of acceptable interference. The studies might even make such agreement(s) a condition of regulatory approval. As cognitive and reconfigurable radios become more readily available, automating some aspects of dynamic adaptation, sharing studies might specify the use of equipment incorporating cognitive capabilities as a condition of regulatory approval for new band sharing arrangements. In general, sharing studies should begin to allow for more conditionality and co-operation between band sharers. This is especially appropriate for light licensing regimes.

### 3.1.2 Coordination for sharing – benefits and pitfalls

This section is a continuation of the previous section, in the sense that it applies to the time after the satisfactory completion of sharing studies.

Coordination has a specific meaning in the context of spectrum management at the international level. It is a process of negotiation between neighbouring states to plan frequency assignments in the area near their common border, in order to reach agreement on permissible levels of transborder interference.

But the word is also used domestically, in a more vernacular sense, as here, to describe the process of developing plans to avoid conflicts between overlapping rights possessed by users, services and systems. Coordination is a striving for unproblematic radio use when a situation is fraught.

However, as Eurostrategy and LS Telecom noted in their study of European models of interference regulation:

> The need for coordination results in inefficient spectrum use. The reason is that, for the sake of fast and easy decision making, the rules have to be simple and reproducible. During the past decade much effort has been expended to improve the mechanics of co-ordination, nevertheless, it is still a fact that further modification of methods and/or modified approaches could lead to significant spectrum gains. Based on our investigations a loss of efficiency of between 30% to 50% of the theoretical possible figure is currently being experienced (Eurostrategy/LS Telecom, 2007).

This example from Finland, cited by the BEREC and RSPG in their joint report on infrastructure sharing, shows what Eurostrategy and LS Telecommean:

[167] ETSI TR 102 967: "Use Cases for Dynamic Declaration of Conformity"

> In Finland the mandatory co-ordination distance for frequency re-use between geographically adjacent service areas has been minimized and in some cases completely removed in the 3.5 GHz frequency band, through voluntary agreements between licence holders. The holders of the same frequency block have agreed on co-existence in the co-ordination area. These agreements have maximized the cumulative service area and contributed to an improved broadband coverage. However, this is not legally possible in some member states (BEREC-RSPG, 2011).

In the previous section we proposed agreements between sharers as a possible condition of regulatory approval of a sharing arrangement, including levels of acceptable interference, the use of cognitive radio techniques if appropriate, accommodation efforts, etc. A continuation of this approach is to allow coordination to modify one or more conditions set when the sharing arrangement was approved. This is the essence of flexible use.

## 3.2. Technical aspects of spectrum sharing in practice

### 3.2.1 Higher performance requirements for receivers

It has often been suggested that setting higher performance requirements for receivers, to improve their selectivity and interference rejection capabilities, would increase the efficiency and socioeconomic benefits of spectrum use.

That claim was analysed in the Eurostrategy/LS Telecom study of interference regulatory models cited in the previous section. The main conclusion of that study was that it "would not be in the interest of economically efficient spectrum use for the Commission to introduce mandatory technical specifications for receivers".

That conclusion, however, did not follow logically from the study's analysis of GSM, UMTS, digital fixed radio systems and DVB-T. Indeed, the opposite conclusion follows. Admittedly, the analysis of digital fixed radio systems showed that receiver improvements would not free additional spectrum in that service. But that was the only exception to an otherwise consistent pattern of gains from stricter receiver standards.

For UMTS, the study found an "achievable capacity increase" of 10-20% from higher receiver standards. That is to say, 10-20% less spectrum would be needed to supply users with the same information carrying capacity. Using what they describe as conservative economic assumptions, that would yield net benefits…

> …considerably greater than the €6.2-12.4 billion indicated.… it would be worthwhile to spend at least an extra €50 per terminal to upgrade the estimated installed base of… 3G terminals… [W]e conclude that the likely costs for introducing the technical improvements discussed would be more than compensated by the economic benefits, and that therefore the 3G industry would probably find this a worthwhile change to make.

For GSM, the study found a 5-15% "capacity increase or bandwidth reduction" from higher receiver standards. That also means a possible reduction in the number of base stations needed for the same capacity. The net present value of the benefits was:

> …considerably greater than the €6.8-20.5 billion indicated… Since the likely manufacturing cost increment per terminal is far less than €15 per terminal in the huge and mature GSM mass market environment for mobiles, we conclude that the costs for introducing the technical improvements discussed will likely be more than compensated by the economic benefits.

For DVB-T the study found that:

if receivers with antenna diversity become a requirement, this would provide a spectrum benefit of 78 MHz [and] "the benefits of releasing 78 MHz… in the UHF TV band will be considerably greater than the €48 billion indicated.

Unfortunately, the study's final recommendation does not make it clear that the authors found at least €62-80.9 billion in net benefits from easily achieved and modestly priced receiver improvements in just 4 services, with the improvements introduced gradually as users replace equipment at the same rates as in the past.

The process of migrating to better receivers will inevitably take time. But given the escalating demands for spectrum, if usage rates cannot be increased within the existing allocation framework, there may be no alternative to mandated receiver improvements. The Commission's previous in-depth assessment of this issue demonstrated that the benefits outweigh the costs by a wide margin, even though the assessment did not recommend the response appropriate to its own findings.

### 3.2.2 Making 2.4 GHz more Wi-Fi friendly

In April 2011, Cisco Systems Inc. submitted an input document to the CEPT Maintenance Group on SRDs suggesting that Wireless Access Systems (WAS) including Radio Local Area Networks (RLANs) operating in parts of the 5 GHz band might be deleted from ERC Recommendation 70-03, the reference document on common allocations for short-range devices (SRDs) in the CEPT countries.[168]

Cisco's suggestion was based on the idea that these WAS/RLANs deserve to be treated differently from "ordinary" SRDs because of the co-primary allocation recommended for them by WRC-03 and because they are the focus of Decisions by the Commission and the Electronic Communications Committee.[169] But Cisco does not see WAS/RLANs as uniquely deserving of special treatment. They used "the 5 GHz WAS/RLANs as an example", noting there may be other "applications with similar protection requirements." As a precedent, they cited ETSI's suggestion that the licence-exempt radio links of medical implants and cardiac devices using the 401-406 MHz band might also deserve greater interference protection than ordinary SRDs.[170]

When WRC-03 recommended co-primary status for WAS/RLANs at 5 GHz, they were careful to state that these devices could not claim protection from the radiodetermination services (radars) which are also co-primary in these bands. Yet the situation is still confusing: a primary allocation generally conveys rights of non-interference. But because WAS/RLANs are licence exempt, they have no non-interference rights. This contradiction arises because the WAS/RLANs at 5 GHz are the first licence-exempt application granted a primary allocation.

Cisco's proposal to differentiate the rights of 5 GHz WAS/RLANs from other SRDs attracted support within the Short-Range Device Maintenance Group, as did France's suggestion that the "SRD concept" needs review and clarification. These matters will be discussed at the next SRD/MG meeting in London on 27-30 March 2012. What we may see is an interference rights gradient emerging within the licence-exempt sector, similar to

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[168] Cisco (2011) Proposed change to ERC Recommendation 70.03, CEPT Meeting Document SRDMG(11)054r1, 6 April

[169] Use of the bands 5 150-5 250, 5 250-5 350 MHz and 5 470-5 725 MHz by the mobile service for the implementation of Wireless Access Systems including Radio Local Area Networks, ITU-R Resolution 229 (WRC-03), endorsed by ECC decision (04)08 [amended 12 November 2004, 5 September 2007 and 30 October 2009], http://www.erodocdb.dk/docs/doc98/official/word/ ECCDec0408.doc

[170] ETSI Liaison Statement FM(11)002. ECC's Frequency Management Working Group (WG FM) is currently considering reclassification of these medical implants as part of the Mobile Service to enhance their interference protection rights. See Weber, T. (2011) Spectrum for Life, ECC Newsletter, June issue, pages 7-9, http://www.wonderlandwpa.com/dev/ecc_newsletter_june/june-2011/images/ECC-Newsletter-june2011.pdf

the spectrum use gradient that emerged between licence exempt and licensed during the past 15 years. There is a gap to fill between no protection and total protection.

One can argue that WAS/RLANs serve the same purpose as WiGig links at 57-66 GHz, Wi-Fi at 2.4 GHz and WAS/RLANs at 17.1-17.3 GHz. Indeed they are treated as a group in ERC Recommendation 70-03: the group is called "wideband data transmission systems". Cisco acknowledged that there may be other licence-exempt "applications with similar protection requirements." Wireless routers, cellular handsets and other consumer electronics with Wi-Fi increasingly pair the 2.4 and 5 GHz bands, to the point that users might not be able to tell which band they are using, or whether they are using both bands together.

Because the 2.4 GHz band is used by so many different device types, and in such large numbers, it is no longer practical to limit it to just one application. Nor is light licensing appropriate for Wi-Fi. Yet it would be possible to take MASS Consultants' suggestion for testing and certifying equipment as "Wi-Fi friendly" and make this friendliness nonvoluntary – an "essential requirement" for authorization to use the 2.4 GHz band.[171] An even bolder measure would be to support all licence-exempt wireless broadband access equipment this way – not the way licensed systems are protected, with regulators intervening to resolve specific interference complaints, but by modifying the requirements for authorization of other equipment sharing spectrum with WAS/RLANs, to make that equipment less likely to interfere with broadband access. Our growing dependence on such access networks and their substantial socioeconomic benefits make it appropriate to privilege them to some extent. A shift in that direction has already begun at 5 GHz.

### 3.2.3 Variable power limits for licence-exempt RLANs

Elsewhere we noted that regulators have been handicapped by the need to set geographically uniform power limits for licence-exempt devices, using the worst case interference scenario as a guide. Invariably that meant letting dense urban deployment determine power levels for the whole country, because there was no way to tell where any particular device would be deployed.

A few years ago, the UK regulator Ofcom recognized that this is inherently unfair to rural areas. Power limits for Wi-Fi, for example, could be increased in sparsely populated regions without significantly increasing the risk of interference. Ofcom suspected that higher power limits would provide significant benefits and cost savings by allowing much larger broadband access areas with no additional base stations.

But before proposing a rule change to permit these higher powers, they asked Scientific Generics (2006) to evaluate the costs and benefits, and recommend an appropriate rural power level. The study showed that the scope for a power increase was enormous, and so were the benefits. The data in Table 3.1 summarizes the findings of the study.

[171] To be specific, Wi-Fi friendliness requirements could be added to ETSI standards EN 300 440 (Non-Specific SRDs); EN 300 761 (Railway applications); EN 300 440 (RFID); EN 300 328 (Wideband Data Transmission Systems); and the appropriate CENELEC standards for Industrial, Scientific and Medical (ISM) devices.

Table 3.1. Rural Wi-Fi power increases and the resulting net consumer surplus

| Cell radius (km) | Frequency (GHz) | Power limit (EIRP) | Net consumer surplus (million GBP) |
|---|---|---|---|
| 3.5 | 2.4 | 1W | 188 |
| 4.25 | 5.8 | 4W | 85 |
| 7.25 | 2.4 | 10W | 443 |
| 7.25 | 5.8 | 25W | 238 |
| 16.5 | 2.4 | 80W | 539 |
| 16.5 | 3.5 | 125W | 287 |
| 16.5 | 5.8 | 200W | 288 |

The table shows net consumer surplus peaking at £539 million when the power limit is 80W. Above 80W higher powers do not translate into higher benefits because at that level the cost of mitigating interference escalates rapidly.

There are several ways to limit deployment of higher power equipment to the countryside. The method is not important because more recent discussions about white space devices, geolocation databases and the proliferation of location aware objects show that this problem is becoming easy to solve.

It is unfortunate that the UK abandoned this innovative proposal. We urge the Commission and the EU member states to reconsider it in light of the Digital Agenda. Adaptive power levels for geographically flexible signal range would make Wi-Fi a far more useful technology, especially in sparsely populated areas where other broadband technologies are more costly.

### 3.2.4 New early warning tools for congestion

In the previous chapter, we noted that an inexpensive tool was used in the UK to detect and monitor Wi-Fi congestion – an internet tablet with GPS and logging software. We also mentioned (in a footnote) a proposal for using census and demographic data to predict congestion. That proved unreliable five years ago, but as Wi-Fi becomes more ubiquitous, the predictive power of this approach may improve (Sandvig, 2007).

CEPT has recognized the need for more active monitoring of conditions in licence-exempt bands. But so far as we know it has not initiated any monitoring of the sort described here, nor is there any agreed protocol for detecting and measuring congestion in the bands used by short-range devices. Perhaps a mandate from the Commission would stimulate activity in this area. In view of the technical challenge of detecting devices with such limited range, the lack of consensus about the maximum sustainable capacity of the bands where RLANs operate, the difficulty of translating user perceptions of service quality into measurable signal features, and the length of time it can take to allocate a new spectrum for SRDs, there is a clear need for early discovery and more accurate assessment of congestion conditions in licence-exempt spectrum. It is also important that the methods used to assess congestion are applied consistently throughout the EU. Therefore, it would be helpful to have a regional conference review and seek consensus on "best practices in defining and detecting congestion in licence-exempt bands" and to mandate a CEPT report on that topic.

Other tools which might be useful in this arena include free downloadable apps for "crowdsourcing" smart phone users. OpenSignalMaps is a good model: its free Android

app automatically collects data about the local strength of GSM, UMTS and Wi-Fi signals wherever the owner happens to be.[172]

During the course of our research we also found that Skyhook, a company which sells access to their global database of 250 million Wi-Fi nodes for the support of location-based applications, is considering developing a free node density mapping tool for regulators.[173]

## 3.3. Sharing exclusive allocations: communicating in radar bands

In the last chapter we noted that most exclusive allocations are for various types of radar, mainly military. A table showing the largest of these bands is found in Table 2.1. Below is an abridgement, showing just the radar bands, with a few notes about their use. These three bands contain 1770 MHz of spectrum:

| Frequency range | Comments |
|---|---|
| 15.63–15.7 GHz | "Doppler radar low power sensing" and "ground movement radar". The latter transmits brief pulses in very narrow sweeping beams to detect and track vehicles on airfield surfaces. |
| 15.7-16.6 GHz | "Harmonized military band for land, airborne and naval radars… [but] can be shared between civil and military users…" 15.7-17.3 GHz was allocated to the fixed & mobile services on a primary basis by Austria, Finland, Montenegro, Serbia & 42 non-European countries at WRC-07. |
| 33.4-34.2 GHz | "Harmonized NATO band… motion sensors; short-range radar; surveying and measurement… mapping, target identification… aim-point determination, test range instrumentation, etc." |

Interference into the systems at 34 GHz could be serious, but sharing in the other two bands seems feasible – and they are continuous. Exclusion zones, transmit power controls, "dynamic frequency selection" and "detect and avoid" rules enable sharing with radars in the 5 GHz band. There have been problems, but learning from those problems could make sharing with radars in other bands less difficult.[174] Without knowing the protection requirements of the systems at 15.63-16.6 GHz, these suggestions are merely indicative:

- At frequencies over 15 GHz, fixed point-to-point and indoor RLAN "hotspots" seem the best candidates for band sharing.
- If the radars are fixed in location, exclusion zones may represent an effective solution. For fixed point-to-point systems, signal paths and antenna patterns can be limited by regulators in consultation with the incumbents to ensure non-interference.

[172] http://opensignalmaps.com/

[173] http://www.skyhookwireless.com/

[174] The 5150-5350 MHz and 5470-5725 MHz bands are used by tactical and weapon system radars, airborne and ground-based weather radars, shipborne and Vessel Traffic System radars, etc. All Wireless Access Systems, including Radio Local Area Networks, operating in the same bands as these radars must be equipped with Dynamic Frequency Selection and Transmit Power Control. However, the diversity of signals which must be reliably detected leads to frequent revision of the ETSI radio interface standards for the WAS/RLANs. Continuing use of devices based on earlier versions of the standard is a growing problem. With sales of 5GHz broadband access devices booming, either software-upgradable WAS/RLANs must become the norm or the evolution of 5 GHz radars will be constrained. The ECC's Work Group on Frequency Management recently started gathering reports of WAS/RLAN interference to the 5 GHz radars in order to assess the scope of the problem (ECC, 2011b).

- Channels used for communication can be chosen to exclude frequencies used by nearby radars (and if necessary, their first-adjacent channels) to reduce the risk of mutual interference, in the case of radars not using pulses.
- If the radar's scanning pattern and frequency use are stable, antenna nulls, filters and other interference cancellers can be built into the communications network.
- By monitoring the radio environment, either the communications systems or the radar systems can dynamically select frequencies which are the least likely to interfere.
- Location awareness for devices controlled by geographic databases, as has been proposed for white space devices in the UHF band, could facilitate band-sharing between radars and licence-exempt "hot spot" devices.
- Band sharing is easier (and can be made more extensive) when incumbent systems are modified to accommodate new band users. In the case of radars, reduction of out-of-band emissions, waveform modifications and newer electronics could expand opportunities for band sharing. But incentives to share and who should pay for system modifications are important issues to resolve. Since some modifications to enable more sharing can also improve radar operation, some costs might be covered as normal system upgrades. But additional costs may have to be borne by the users benefitting from increased spectrum access, either as part of the cost of their licence or as negotiated with the incumbent. If the organizations operating the radars could add income from "spectrum sublets" to their budget, this would be an incentive for them to make spectrum available for shared use.
- Licensed Shared Access (LSA) or Authorised Shared Access (ASA) could be a suitable regulatory frameworks for developing relationships of trust and cooperation between private-sector network operators and governmental radar system operators. Trust and cooperation will be needed if there is to be any sharing of sensitive information regarding radar system requirements and deployments. If the relationships prove long-lasting, they might even lead to cooperation in developing future systems with improved coexistence characteristics.
- Sharing would be most difficult in bands where mobile and airborne radars can be deployed without warning for uncertain durations.

## 3.4. New authorization classes – shared assignments

*…an authorisation regime without regulatory conditions to use spectrum does not exist.*[175]

The first international radio treaties introduced licence requirements for non-governmental stations. Even today, the ITU radio regulations state that:

> no transmitting station may be established or operated by a private person or by any enterprise without a licence issued in an appropriate form and in conformity with the

[175] Impact of the trend towards flexibility in spectrum usage on the principles for drafting Harmonized Standards and the ETSI work programme for Harmonized Standards, ETSI TR 102 748 V1.1.1 (2008-03), http://circa.europa.eu/Public/irc/enterprise/tcam/library?l=/public_documents/tcam_25/flexibility_reportdoc/_EN_1.0_&a=d

> provisions of these Regulations by or on behalf of the government of the country to which the station in question is subject.[176]

At first, it was clear: either one had a licence or one did not. But with the introduction of "class licenses" – issued automatically, with no need to fill out an application form – and "type licenses" – provided with the purchase of approved equipment – the concept of a licence was so diluted that class and type licenses were used to approximate licence exemption in countries where licenses were still legally required but the regulator considered them practically unnecessary for the use of certain bands.

Eventually, the realization spread among regulators that licensing is just one type of authorization and other authorizations might be sufficient in certain situations. Even without licensing, regulatory control can be asserted through what is now called the radio interface specification, which sets technical standards for equipment performance, and through band-specific conditions attached to general authorization.

With the Authorization Directive (2002/20/EC) the Commission took the position that licensing – or the granting of "individual rights of use" – should be limited to situations where it is "unavoidable" or necessary for efficient use:

> Member States shall, where possible, in particular where the risk of harmful interference is negligible, not make the use of radio frequencies subject to the grant of individual rights of use but shall include the conditions for usage of such radio frequencies in the general authorisation.[177]

There are limits on conditions that may be attached to general authorization, as it conveys a general right to provide electronic communication services and create networks. Nevertheless, even while limiting the use of licensing, the principle that all uses of radio must be *authorized* is affirmed.

Ten years have passed since the Authorization Directive was issued. One might have thought that by now large parts of the radio spectrum would no longer be "subject to the grant of individual rights of use". But that is not the case. Change is proceeding glacially and one must ask why? In fact, CEPT asked why 5 years ago, in a survey of regulators for ECC Report 83: "Licence Exemption and its Impact on the Funding of the Radio Administration"[178] After noting that hardly any problems were reported by administrations after the introduction of licence exemption or the de-licensing of previously licensed services, the report observes that:

> only one risk was mentioned by respondents, while a long list of benefits could be drawn out of all the comments made. This stands in contrast with the current extent of licence exemption or with the relatively low number of administrations that intend to exempt further applications in the future.

The only explanation offered for this inertia was that most of the early decisions to do away with licensing were made by individual countries without much coordination with their neighbours and peers, so that the momentum behind specific changes quickly dissipated. Conversely, the author of the report concludes, "administrations are more likely to embark on exemption when a harmonised CEPT or EU approach is taken."

The NRAs indicate that a harmonized approach would produce quicker movement toward general authorizations, so here is a clear opportunity for leadership at the regional level.

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[176] Article 18.1

[177] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0020:EN:NOT

[178] http://www.erodocdb.dk/docs/doc98/official/pdf/ECCRep083.pdf

With licensing deprecated and limited enthusiasm for exemption, European regulators began devising new authorization classes in the gap between licensed and unlicensed, as shown in this table from ECC Report 132 (2009).

Table 3.2. Characteristics of different authorization regimes

| **Individual authorization (Individual rights of use)** | | **General authorization (No individual rights of use)** | |
|---|---|---|---|
| *Individual licence* | *Light licensing* | | *Licence exempt* |
| Individual frequency planning / coordination.<br>Traditional procedure for issuing licences. | Individual frequency planning / coordination.<br>Simplified procedure compared to traditional procedure for issuing licences.<br>With limitations in the number of users. | No individual frequency planning / coordination.<br>Registration and/or notification.<br>No limitations in the number of users nor need for coordination. | No individual frequency planning / coordination.<br>No registration or notification. |

Source: ECC Report 132 (2009)

"Light licensing" was defined in ECC Report 80 as:

> …a combination of licence-exempt use and protection of users of spectrum. This model has a 'first come first served' feature where the user notifies the regulator with the position and characteristics of the stations. The database of installed stations containing appropriate technical parameters (location, frequency, power, antenna etc.) is publicly available and should be consulted before installing new stations. If the transmitter can be installed without affecting stations already registered the new station can be recorded in the database. New entrants should be able to reach an agreement with existing users in case interference criteria are exceeded. The regime can enable the SMA [spectrum management authority] to protect a limited number of sensitive sites while giving greater flexibility elsewhere than could be allowed without the geographical limitation.

But not everyone defined "light licensing" that way. Indeed, one of the purposes of ECC Report 132 was to decide whether interpretation of that phrase should be harmonized, presumably to accelerate the uptake of light licensing. But the answer given by the report was not yet: there is still value in exploring and experimenting with shades of lightness in licensing.

Comments submitted by Silver Spring Technology for the workshop preceding the release of this study drew attention to another, more market oriented interpretation of "light licensing":

> Operators or those deploying the technology… [could] pay a fee for its technology to be used in the band. In this way access to the band can, if necessary, be restricted to those applications that have the most significant socio-economic benefit. The fee structure can be tiered, so that smaller entities such as SMEs are not barred from access to the band so long as they adhere to the terms of the light-license (eg, restriction on what applications can be run, duty cycle, etc).[179]

From our perspective, the growing diversity of authorization classes gives regulators many ways to map the needs of end-users, equipment developers, services and markets onto the characteristics of virtually any wireless communication technique. Since the starting point

[179] From Silver Spring Technology's written response to the question: "How can wireless innovations help to better utilise the radio spectrum?"

for most existing allocations is traditional licensing, all these variations provide pathways to reducing the constraints of licensing.

Light licensing has the potential to replace traditional licensing in many bands and services – so much so that it is not easy to list all the contexts where it would be appropriate. But maritime mobile is an appropriate place to start, for pleasure boats, fishing vessels and the like are obvious candidates for light licensing, even for de-licensing – and some Member States have already moved in that direction. Denmark started delicensing its maritime service 15 years ago.

Recognizing that propagation distances above 100 GHz are limited and directional antennae are easily constructed, the overall risk of interference in the higher GHz bands is significantly less than in lower bands. As a result, several administrations have looked into the option of making licence exemption or light licensing the default authorization schemes above a certain frequency.[180] We support these proposals and believe they are what the Authorization Directive requires.

### 3.4.1 Authorised Shared Access (ASA)

ASA is an authorization scheme proposed by Qualcomm and Nokia in a joint response to the RSPG consultation on cognitive technologies in January 2011.[181] It was subsequently refined in a report and presentation to the 28th ECC meeting (7-11 March 2011)[182] and in a May 2011 presentation to the CEPT Working Group on Frequency Management.[183] WG FM asked their correspondence group on cognitive radio systems to analyse ASA without tying it to any particular use case or frequency band and suggest a way forward. The CRS group's preliminary analysis was presented in October 2011[184] with further consideration planned for 2012.

ASA would use cognitive techniques – beacons, geolocation databases, sensing, etc – to enable one or more new licensees to exploit spectrum assigned to one or more incumbent licensees when the spectrum is not actually needed by the incumbent(s). ASA thus offers a mechanism for spectrum users to grant a limited number of others temporary access to their assigned frequencies. It differs from traditional band sharing in that:

- ASA is based on the use of cognitive radio techniques to determine channel availability, and
- ASA envisions bilaterally negotiated and regulator recognized agreements between new and incumbent users to set the conditions for frequency access. These conditions might include compensation to the incumbent(s) for agreeing to share. In return the newcomer would gain an assured amount of spectrum availability, in

[180] Ofcom UK (2007) Licence-Exemption Framework Review, http://stakeholders.ofcom.org.uk/binaries/consultations/lefr/statement/lefr_statement.pdf

[181] See http://rspg.groups.eu.int/consultations/consultation_cognitiv_2010/qualcomm_nokia_0114.pdf; discussed in Standeford, D. (2011) Qualcomm and Nokia propose Authorised Shared Access to spectrum, *PolicyTracker,* 30 March.

[182] Ingenious Consulting Network (2011) Authorised Shared Access: An evolutionary spectrum authorization scheme for sustainable economic growth and consumer benefit, 20 January, ECC(11)INFO01 and ECC(11)INFO06

[183] Meek, K. (2011), Authorised Shared Access: an evolutionary spectrum authorisation scheme for sustainable economic growth and consumer benefit, presentation to CEPT WG FM, 17 May, http://www.cept.org/Documents/cg-crs/363/CGCRS_11_07_Presentation_of_ASA_concept__FM_11_116 _Attachment_

[184] See Annex 1 of CEPT Meeting Document FM(11)159.

the form of a guaranteed minimum amount of spectrum use time in certain geographic areas, perhaps with advance warning when access will be suspended.

ASA also differs from CEPT's WSD proposal in that the opportunistic users would be licensed, limited in number and subject to the terms of an explicit agreement with one or more incumbents. (Under WSD rules, there are no negotiations with incumbents, the number of opportunistic users is unlimited, their identities unknown.) The resistance incumbents have shown to proposals for WSD access to the UHF band suggests a need for a more controlled sharing arrangement and ASA gives incumbents more incentives and control over the details of sharing while still promising more spectrum utilization as with the WSD scheme.

In our study we consider access to the exclusive bands used by various radar systems as a potential source of "new" shared spectrum. So it seemed significant when the UK Ministry of Defence recently announced "short term sharing opportunities" in the 3500-3580 MHz band under a scheme resembling ASA, and they invited the public to register their interest in paid access to five additional frequency bands.[185] This demonstrates that wary sharers can become willing partners if given a say in who shares with them and an opportunity to gain compensation. Thus we see ASA – and the variant proposed by the RSPG, Licensed Shared Access (LSA) – as particularly attractive for new sharing arrangements between incumbent governmental primaries and commercial secondaries (Bykowsky/Marcus, 2002).

However, ASA need not be limited to specific bands or use cases – or only applied to "new users" and "incumbents". It should work the same way when only incumbents are involved, and whether they have equal or unequal regulatory status. In fact, one can see ASA's origins in a 2008 study by Heinonen, *et al,* of efficiency gains from various spectrum sharing arrangements among cellular operators. One arrangement, called "sharing as a secondary user" clearly resembles ASA. Another, called "sharing as a last resort", has different rules, and "always connected to the least loaded", differs in other ways. The study shows that the different sharing arrangements work best under different traffic conditions. Therefore the efficiency gain (and thus the benefit) cannot be reduced to a single number: it appears as a range of possible values. Second, the ASA-like arrangement ("sharing as a secondary") produced the least gain of the three cases. The gain was still significant, however. So the authors conclude that "when resources are shared among operators, spectrum efficiency is improved, and hence, a better quality of service can be provided for customers".[186]

In the 2008 study the sharers are all mobile network operators, which raises a different set of issues than when the sharing is between different services. When regulators establish a frequency sharing relationship among licensees, one expects them to be impartial and motivated by public interest obligations. When a private licensee sets up a sharing arrangement with a competitor, one must wonder about the motive and the impact on competition. If one cellular operator is able to help or hinder a rival by sharing or withholding a "bottleneck resource", this is an exercise of market power which necessarily raises competition concerns. Similar issues were encountered in Chapter 2's discussion of infrastructure sharing.

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[185] UK Ministry of Defence Statement: Sharing Defence Spectrum, http://www.mod.uk/DefenceInternet/AboutDefence/WhatWeDo/ScienceandTechnology/Spectrum/

[186] Heinonen, V., *et al.* (2008), "Capacity gains through inter-operator resource sharing in a cellular network", in Proc. IEEE WPMC, http://www.ee.oulu.fi/~pekkap/WPMC08_VH_PP_JI.pdf (research partly financed by Nokia and Nokia Siemens)

However, cooperation among competitors is not what ASA's supporters proposed in 2011. ASA combines elements of traditional "command and control" administration with a more market-oriented approach and innovative cognitive radio techniques. In that sense it offers a novel mix of old and new ideas about non-exclusive frequency use. Since adaptive sharing is a clear improvement over exclusivity and static/persistent channel assignments, we welcome the proposal.

### 3.4.2 Licensed Shared Access (LSA)

LSA takes ASA as its starting point but shifts the emphasis in important ways. First, ASA is a framework for sharing among *licensed* users, even though the name ASA refers only to *authorized* use. LSA corrects that by putting licensing up front.

The Radio Spectrum Policy Group defines LSA as:

> An individual licensed regime of a limited number of licensees in a frequency band, already allocated to one or more incumbent users, for which the additional users are allowed to use the spectrum (or part of the spectrum) in accordance with sharing rules included in the rights of use of spectrum granted to the licensees, thereby allowing all the licensees to provide a certain level of QoS. (RSPG, 2011).

LSA takes on board ASA's use of cognitive radio techniques to determine spectrum availability and bilaterally negotiated agreements on guaranteed minimum channel availability. But LSA treats a new agreement on temporary transfers of frequency use rights as a "change of use" for an exclusive assignment. As a result, LSA would have the "sharing rules included in the rights of use of spectrum granted to the licensees". In other words, the "sharing rules" negotiated by the licensees must be approved by the regulator and incorporated in their licence conditions as amendments or replacement licenses. Treating "sharing rules" as new licence conditions would make adherence to the rules a strict requirement and make any subsequent rule changes more difficult to achieve, if the arrangement does not work as the licensees had hoped. Under ASA, the role of the regulator is much less decisive.

LSA is also less concerned with the kind of sharing arrangements that might be negotiated than with the need to harmonize the conditions enabling the negotiations. This is an issue because implementing ASA and/or LSA might not be legally possible in all EU member states. Since payments are foreseen for short-term transfers of spectrum use rights, ASA and LSA can be considered subleasing arrangements, and a survey conducted for ECC Report 169 found that at least 11 CEPT administrations do not permit spectrum subleasing: Croatia, Czech Republic, Estonia, Ireland, Lithuania, Malta, Romania, Russia, Slovenia, Sweden and Switzerland.[187] (Spain may be in this group, too, but it did not answer the survey.[188])

RSPG "intends to undertake further work on the concept of LSA… which will be subject to a public consultation". In this regard the RSPG also recommended "that the EC should consider the implementation of the LSA concept in order to provide access to new spectrum in the light of the future RSPP Decision" and that "a first step could be a consultation of the Member States to gather complete information on the licence regimes of the MS, in relation to sharing" (RSPG, 2011).

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[187] Description of Practices Relative to Trading of Spectrum Rights of Use, ECC Report 169 (May 2011), http://www.erodocdb.dk/docs/doc98/official/pdf/ECCRep169.pdf

[188] BEREC-RSPG Report on Infrastructure and Spectrum Sharing in Mobile/Wireless Networks, BoR (11), June 2011, notes that Spain forbids the joint exploitation of frequencies originally assigned to one operator. http://erg.eu.int/doc/berec/bor_11_26.pdf

### 3.4.3 Dynamic/opportunistic access and its authorization

Dynamic/opportunistic access is a term associated with 'overlay' in the sense of adding to a band already partly occupied. Such access is also associated with cognitive radio.

CEPT has been studying the technical requirements for implementing a real-time geographic control system in the 470-790 MHz band, where digital terrestrial television (DTT) is the primary service, wireless microphones can be deployed for programme making and special events (PMSE), and sub-bands are allocated for radioastronomy and aeronautical radionavigation. Opening the UHF band to sharing is attractive because of the excellent propagation, and the fact that DTT has static channel assignments and large buffer zones scaled to prevent interference from other DTT stations. Since DTT coverage concentrates in areas of high population density, the buffer zones ("white spaces") tend to encompass areas of low population density. It seemed a reasonable hope, therefore, that rural broadband access networks might develop in white spaces, taking advantage of the long reach of UHF signals and cost-free access to licence-exempt spectrum.

But is there enough white space in the UHF band to attract equipment developers to develop new applications? The answer to that question depends on how much protection regulators decide to give to DTT. Maximum protection is achieved with no use of white space at all, and that is what broadcasters prefer. But others have set more moderate protection levels and modelled propagation through the landscape, finding in some cases that there could be enough white space to support many new uses. Table 3.3 summarizes one research group's estimates. Note that each "channel" is 8 MHz, so the average amount of spectrum available as "white space" is about 160 MHz per country.

Table 3.3. White space availability in 11 European countries

| COUNTRY | WHITE SPACE BY AREA | | WHITE SPACE BY POPULATION | |
|---|---|---|---|---|
| | AVERAGE NUMBER OF CHANNELS AVAILABLE | FRACTION | AVERAGE NUMBER OF CHANNELS AVAILABLE | FRACTION |
| CZECH REPUBLIC | 13.4 | 34% | 14.1 | 35% |
| GERMANY | 19.2 | 48% | 17.7 | 44% |
| LUXEMBURG | 21.5 | 54% | 19.8 | 50% |
| UNITED KINGDOM | 23.1 | 58% | 20.4 | 51% |
| SWEDEN | 25.6 | 64% | 21.4 | 54% |
| AUSTRIA | 21.1 | 53% | 22 | 55% |
| NETHERLANDS | 23.7 | 59% | 23.7 | 59% |
| DENMARK | 24.4 | 61% | 24.1 | 60% |
| SWITZERLAND | 25.3 | 63% | | |
| BELGIUM | 25.6 | 64% | 25.2 | 63% |
| SLOVAKIA | 26.1 | 65% | 25.8 | 65% |
| ALL 11 COUNTRIES | 22.5 | 56% | 19.8 | 49% |

Source: van de Beek (2011)

ECC Report 159[189] offers interim recommendations for the use of geo-location databases to control the operating frequencies and power output of "white space devices" (WSDs). The report concludes that signal sensing by individual WSDs is too unreliable for detecting occupied channels, particularly the channels used by wireless microphones. Many implementation details for the geographic databases are left to national administrations to decide. Since the mandate to those who drafted ECC Report 159 was to "ensure the protection of the incumbent radio services" – not to define the least restrictive technical conditions or maximize opportunities for band sharing – the emerging framework for WSD regulation in Europe looks like it could be more restrictive than in the USA.

Our survey of national regulatory authorities found a great deal of professional interest in the policy questions posed by WSDs but limited support for authorizing them. Only Belgium, Denmark, Finland, Latvia, Poland, Slovakia and the UK said they now plan to authorize WSDs, although Bulgaria, Portugal and Spain remain undecided. If few countries authorize WSDs, and the technical requirements are more burdensome, the potential market will be smaller and the less interest equipment developers will have in creating new products. Even now, no "killer application" has emerged to generate entrepreneurial excitement. Rural broadband access networks are a recurring hope. But utility meter reading and M2M links have more reliable demand, and the cellular industry waits patiently, hoping to bridge their existing allocations with as much of the 470-790 MHz range as they can get.

Geolocation database control of wireless devices is a potentially powerful new tool for regulators. It is likely to find useful applications in more parts of the spectrum than just 470-790 MHz, for it solves two important problems. Previously, because regulators had no way of knowing where any particular licence-exempt device would be deployed, every SRD of a certain type had to have the same maximum power output, and that "one size fits all" limit had to anticipate the worst case scenario. Areas likely to have lower deployment densities (ie rural areas) were deprived of the possibility of having a higher power limit and thus a longer signal range, as would be appropriate for their circumstances, because of the need to consider what might happen in dense urban deployments. However, with location awareness, the power output of each device can be set *after deployment* to a non-interfering level appropriate to that locale.

The other major problem this solves is how to disable licence-exempt devices if the band is re-allocated to a licensed service. Devices controlled by a geolocation database cannot transmit until they receive permission from the database, and in the case of re-allocation, permission can simply be denied.

On the other hand, giving regulators an "on/off switch" to control large numbers of Internet access and communication devices entails political risk. As was demonstrated in other parts of the world last year, if a government wants to manipulate or cut off access to the Internet in a crisis, selectively or for all, it can be done, though with difficulty. The geo-database infrastructure, on the other hand, could make it easier.

## 3.5. User owned infrastructure

Most governmental and PMR systems can be considered "user owned" so there is nothing new or unusual in the idea. But a community of volunteers building and operating their own telecommunication infrastructure is unusual when the norm is buying "prefab"

[189] Technical and Operational Requirements for the Possible Operation of Cognitive Radio Systems in the 'White Spaces' of the Frequency Band 470-790 MHz (Cardiff, January 2011), http://www.erodocdb.dk/docs/doc98/official/Pdf/ECCRep159.pdf

services from large corporations. In this section we will explore some variations on this theme, which seems to go hand-in-hand with giving users of the radio spectrum more freedom to define their systems and manage their own frequency use.

The notion of user-owned community networks predates Wi-Fi by several decades. It represents an important early strand in the development of wireless data networks, and is equally important as an option for ubiquitous and sustainable networks in the future.

Radio amateurs in Canada began experimenting with VHF transmissions of ASCII in 1978, soon after the first personal computers appeared on the market. In 1981, the Federal Communications Commission proposed to let radio amateurs in the US experiment with "spread spectrum", a little-known signal format used for unjammable "stealth" links by the military. The FCC approved civilian use of spread spectrum in 1985. Not just licensed amateurs, but anyone could use it for any purpose in three of the bands for Industrial, Scientific and Medical (ISM) applications:

> The key feature of these rules [was that they did] not limit the use of this unlicensed spectrum to any specific class of use or users. As the [Notice of Proposed Rule Making] had stated, they 'would allow the forces of the marketplace to drive the implementation of this new technology, unhampered by regulations other than those needed to prevent harmful interference to licensed systems'… The rules adopted in Docket 81-413 had a much greater impact than any of its advocates could ever have imagined...[190]

A few months later, Donald Stoner submitted a petition to the FCC requesting the allocation of the 52-54 MHz band for the creation of a licence-exempt "Public Digital Radio Service":

> Presently, computer-to-computer communication by the general public is confined to the telephone network. Millions of computer owners find that it is increasingly expensive to utilize this network to satisfy their communication needs. Establishment of the Public Digital Radio Service would permit the owners of personal computers to communicate by radio. Instead of a traditional channelized scheme, the petition describes a radio Local Area Network (LAN). The Public Digital Radio Service permits an infinite number of local area radio networks to be interconnected into a national packet radio network… at no cost.[191]

The FCC rejected Stoner's petition, but his idea – embraced by personal computer owners and opposed by the licensed radio industry – provoked intense debate. By the early 1990s, the significance of data communication was recognized, and it was realized that a mesh of low power radio relays, not owned by any outside enterprise, could cover whole neighbourhoods, linking computer owners to each other, to distant neighbourhoods and to information resources everywhere. Net activists saw co-operative not-for-profit wireless networks as low cost yet user empowering. Starting such networks became a crusade, particularly in Eastern Europe. The first city-wide wireless internet access network in Europe – Latnet – was created in 1993-6 by graduate students at Riga University in Latvia, initially using modified Amateur radio equipment from America. They went on to help seed similar networks in 30 other countries.[192] Many community wireless pioneers went on to become commercial wireless internet service providers, managers of national

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[190] Michael Marcus, "Wi-Fi and Bluetooth: the path from Carter and Reagan-era faith in deregulation to widespread products impacting our world", info, vol. 11, no. 5 (2009), pages 27 and 33 - http://www.marcus-spectrum.com/resources/WiFi-rev.pdf

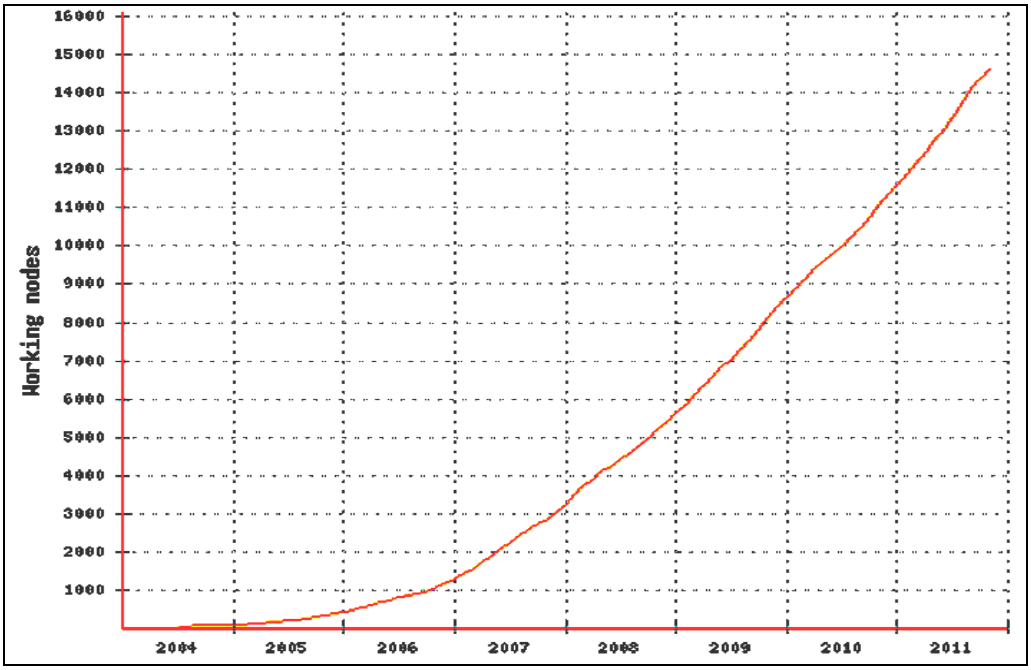
[191] Stoner, D. L. (1985) Petition for the Creation of the Public Digital Radio Service, reprinted in FidoNews, 2 February 1987, http://www.wps.com/FidoNet/FidoNews/1987/FIDO405.NWS

[192] Barzdins, G., *et al.* (1999) Applications of High-Speed Wireless Solutions for Developing Countries: Lessons Learned in Latvia and Moldova, presented at INET-1999, http://www.isoc.org/inet99/proceedings/4d/4d_2.htm

academic-research networks or equipment designers. MikroTik, the Latvian firm which makes the RouterBoard (discussed in Chapter 2), began by making equipment for Latnet.

Europe is home to some of the largest community wireless networks in the world (see Appendix D). Guifi.net, founded in 2004, currently serves 14,700 homes and businesses in Catalunya, Spain, most of them in rural areas.[193] As Figure 3.2 shows, about 100 new members join every week. Guifi.net is organized as a voluntary association linked to a non-profit foundation which is legally registered as the network operator. Until recently there was no paid staff. There are now 2 employees.

Figure 3.2. Guifi.net - an example of the growth of community wireless




Source: Guifi.net

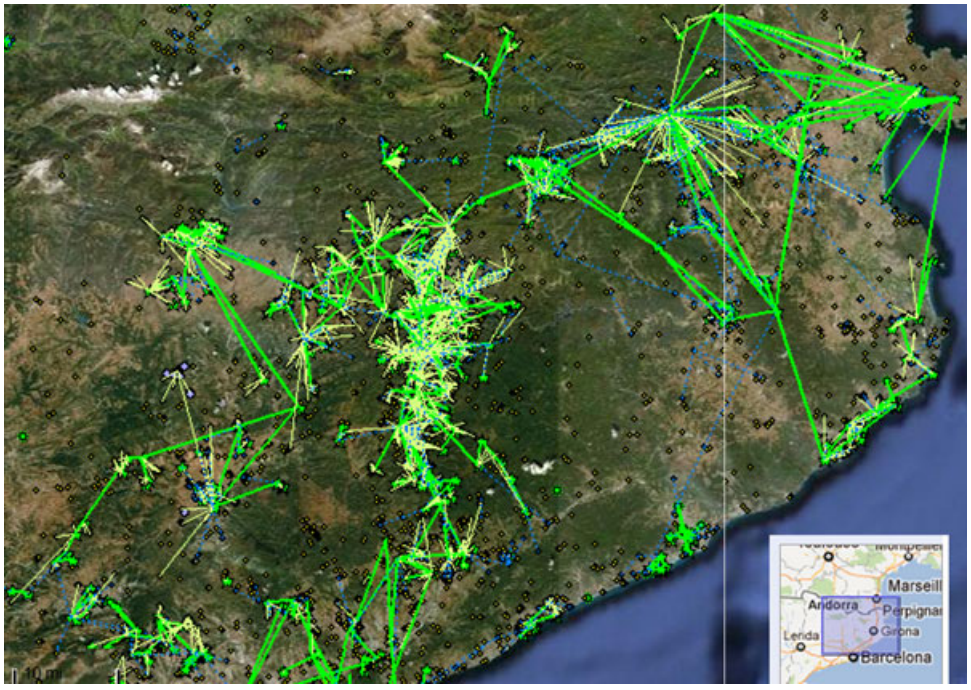
In 2009, Guifi.net started building an optical fibre "backbone" which connects to the Internet at Barcelona's Telvent Carrierhouse peering exchange. This enables them to bypass all intermediaries and resellers, and obtain high speed access (over 1 Gbps) at wholesale prices for their members. Money to pay for the backbone was raised from the membership ("crowd-sourced") and from municipal governments along the fibre's path, in exchange for bandwidth to support city services. The backbone is expected to be about 200 km long, eventually.

Each member must find a way to connect to the network. Usually this is done with a Wi-Fi link to an already-connected neighbour. A one-time investment of about €200 for equipment and installation is usually sufficient. Apart from the backbone, Guifi.net is a mesh of peering agreements among friends and neighbours who decide among themselves how to share out the connectivity costs (usually €10-€20 per month). There is no central accounting, billing or collection system, so the foundation has only the vaguest idea what the network's total annual turnover is. One of the founders, Ramon Roca, believes it is €700,000 - €1,000,000, not including the cost of backbone build-out.

[193] http://guifi.net. See, too, their page on the Commission's Bottom-Up Broadband server: http://ec.europa.eu/information_society/events/cf/dae1009/item-display.cfm?id=5490

A list of community wireless networks in Europe is found in Appendix D.

Figure 3.3. Part of Guifi.net's 24,300km of wireless links




FON is a very different sort of user-owned network.[194] Over four million of their Wi-Fi routers have been sold or otherwise distributed. They split each user's bandwidth into private and sharable channels. The splitting enables the user to keep his part of the bandwidth encrypted and secure while sharing the rest of the bandwidth with other FON users – or with the general public.[195] In exchange, he gains the right to access the shared bandwidth in anyone else's FON node. Roamers can easily recognize a FON access point because the names always begin with the syllable FON.

FON has signed agreements with some large commercial telecom network operators – Belgacom, British Telecom, e-Plus, Mobile TeleSystems, SFR, etc – enabling their customers to use FON access points for free, too. This is an ingeniously simple way to share the benefits of having a Wi-Fi network without exposing private data to intruders. And since the arrangement is reciprocal, the problem of freeloading is solved while an incentive is created for sharing which increases in value as the number of "FONeros" rises.

Cellular networks are already exploiting user-owned infrastructures by encouraging their subscribers to buy or install femtocells and to offload internet data transfers to their own or public Wi-Fi access nodes. And as we have repeatedly noted, user-owned Wi-Fi is the most prevalent method of Internet access.

One of the "winning ideas" from the Digital Agenda Stakeholders' Day in October 2010 was "Bottom-Up Broadband". As implemented on the Digital Agenda website, this is a

[194] http://corp.fon.com/ FON (the corporation) is a business which makes and sells the routers described above. They also keep part of the fees paid by the public for accessing FON "hotspots", and collect fees from large telecom operators for letting their customers access FON "hotspots."

[195] If the public is charged an access fee, the fee is collected by PayPal and shared with FON.

template and archive for sharing information about grassroots initiatives like Guifi.net, FON.[196] Community wireless activists had sought a modest level of EC Regional funding six years ago, for activities they thought would encourage more broadband projects in underserved rural areas. Their ideas with a spectrum reform component were:

- increase the radiated power limits for licence-exempt WAS/RLANs in rural areas.
- allow more freedom in the choice of antennas for WAS/RLANs in areas where the risk of interference is low (in some member states, licence-exempt equipment can be used only with the integral antenna supplied by the manufacturer; customization with directive antennas for longer link paths is not permitted).
- Permit the use of "white space" frequencies below 220 MHz on a licence-exempt basis in rural areas.

## 3.6. Possibilities for repurposing and refarming

### 3.6.1 General incentives for incumbents to accept sharing or relinquish bandwidth

Refarming is a set of measures (administrative, economic and technical) aimed at recovering a frequency band from its current users so it can be re-assigned, either for new uses or for the introduction of more spectrally efficient technologies.

Economic mechanisms to reshape the behaviour of incumbents may take the form either of penalties whose nature becomes more onerous with time or inducements with benefits. The concept of spectrum rent set at 'market prices' is unknown to many public bodies and even to some entrenched players in the private sector, such as broadcasters, if they retain their earlier spectrum allowances.

Another form of incentive is to permit incumbent licence holders to participate in the returns from other users if they relinquish their exclusive rights to a swathe of spectrum. This mainly applies to the public sector. However, in the commercial markets of broadcasting and mobile cellular new forces for sharing may emerge in the next few years.

### 3.6.2 The case of the military and public services – AIP and its successes

The establishment of an effective spectrum management regime for the public sector is essential. Incentives for the public services were studied by Ofcom in the UK under its Independent Audit of spectrum holdings, during the Spectrum Framework Review of 2004/5. Among the final results was the recommendation to expand the use of Administrative Incentive Pricing, AIP, in order to induce more efficient use of public sector spectrum (see Box below).

In addition to AIP, the Independent Audit also endorsed band sharing between the public and private sector via geographic, temporal or technological reuse of bands, particularly where the primary use is not continuous or nationwide. This may be enhanced by building on existing sharing techniques and arrangements (those explained above) by incentivizing the bodies which manage the bands to admit more sharers (for example by reducing their AIP charges commensurate with the value of sharing permitted), or by allowing the bodies to keep the income generated from sharing arrangements if agreed by the administration.

[196] http://ec.europa.eu/information_society/events/cf/dae1009/item-display.cfm?id=5259

**Box 3.1. Administrative Incentive Pricing (AIP)**

AIP is a fee charged to users of the spectrum to encourage them to make economically efficient use of the spectrum. Licences issued through an administrative process, possibly on a first come first served basis, carry with them an obligation to make a regular payment to the regulator or government agency. The idea is that AIP will give the owner of the licence an incentive to return unused spectrum or share it with the private sector rather than pay the entire fee.

**The theory behind the use of AIP**

The theory behind AIP for public services is that it promotes efficiency more effectively than trading, in cases where government services such as the military are important spectrum users. The reasoning is that such agencies may be more responsive to an actual cost burden than to an opportunity cost with trading, as cost minimization is likely to be an important objective for such entities. AIP is held to promote efficiency more effectively where trading has been slow to emerge, or where the best way to define the rights to be traded is unclear, as has often been the case with secondary trading.

There may be significant problems owing to public sector bodies' investments in equipment which may act as barriers to relinquishing or sharing spectrum or moving to another band. For example, the amortization of high capex items, such as radar transmitters, may present difficulty. Although it is possible to reduce the spectrum required and even vacate frequencies altogether during equipment conversion from analogue to digital there may be budget constraints. In the latter case, long procurement cycles and then long lifecycles in operation have been designed to operate generously, over whole bands, even if this might not be necessary for technical reasons. It is therefore unlikely that changes to such spectrum holdings will be made quickly.

## 3.7. The changing position of broadcasting and mobile incumbents

### 3.7.1 The case of broadcasting

European broadcasters have strongly resisted changes in their spectrum allocations, while close relationships with political establishments have cemented the protection of their claims as a public service obligation. Until recently, especially during the move to digital switchover, the broadcasters appeared to want to give up as little bandwidth as possible, despite the encroachments of satellite and CATV into terrestrial broadcast audiences.

But a change may be coming. Release of significant spectrum resources under the current round of the digital dividend showed that flexibility is possible in the broadcast TV markets and that new technology could dissolve the rigidity of the analogue past. New commercial forces may be modifying these traditional positions as a rethink of the broadcast model for digital markets is now in full swing. Various uses of IPTV over the internet are having a major impact, demonstrating where future entertainment audiences will look for content and at how they want to be served. Using the internet as the distribution medium is now being considered by all major TV and radio broadcasters. The success of the BBC iPlayer has shown the way forward. If it is to survive, the industry needs to expand into internet TV, downloads and streaming – where their digital assets may attract a worldwide audience. The mobile internet is going to be as important for broadcasters in a tablet world as fixed broadcasting was in the analogue world. The MNOs already realize that broadcasters could be future content providers.

Broadcast industry support for spectrum sharing with mobile broadband, with a potential release of spectrum for a large licence-exempt commons for RLANS (tablet owners choose Wi-Fi connectivity wherever they can) will advance their future business models and create new markets for their content.

### 3.7.2 The case of cellular mobile – 2G, 3G and 4G

Regulators, economists and policy makers have too often made the mistake of thinking that the mobile industry regards spectrum as an economic asset, to be exploited as a revenue and profit generating resource. However the reality is that, at board level, spectrum is regarded as the ticket to market entry and a weapon against competitors. It thus commands enormous premiums in those bidding situations which allow the deepest pockets to show their power. It is hard to imagine the cellular industry sharing frequencies with noncellular users, as this would be against its market control impulses.

However with the move to data traffic generated by internet access and high value multimedia content, all is thrown into question. Either with or without the media industries and internet players, the MNOs are now both frightened by the prospect of mobile internet access (ie by Skype-style voice revenue drain) and entranced by the promise of downloaded multimedia and advertising revenue streams. So there now may be powerful commercial reasons for sharing spectrum and going into licence-exempt bands for internet access and video offloads.

Today's mobile industry sees LTE is the next great mountain to climb, a way to churn the EU market again That churning needs a tangible deliverable – mobile internet is the extra functionality. So if offloading is the way forward – then that is likely to be the next industry lobbying goal.

MNOs may thus be quietly rethinking the whole spectrum play across the industry for fear of missing out on mobile internet take-off, as they would have to put data caps on internet use. They might then cede all to the fixed line and cable operators with Wi-Fi hubs in the home or reinforce their core networks for this task.

It is possible that an engulfing mobile internet could also have spin-off effects on other key revenue sources – roaming and national termination charges. Using local internet access via Wi-Fi undermines the traditional cellular industry charging models as users look for a competing ISP (or WISP) offering VoIP services (Skype or other) at lower cost. This competition could bring down roaming charges and reduce termination charges nationally.

## 3.8. The impact of shared spectrum access on mobile roaming

### 3.8.1 The mobile roaming situation in the EU

The Digital Agenda for Europe sets a goal of narrowing the differences between roaming and national tariffs to near zero by 2015. Inadequate competition is recognized as the root cause of the unjustifiably high prices for international data roaming services. Yet there is also recognition that price caps do not increase competition. However, increasing competition from non-cellular networks in shared access spectrum could help drive down the retail prices of cellular roaming services. Why is this necessary? A Commission staff paper explains:

> Many Europeans avoid, or curtail, usage of their mobile phones when travelling outside of their home Member State in order to avoid incurring mobile roaming charges. Every day European businesses and citizens are faced with the reality that this bottleneck to cross-border activity remains. The weak linkage between cost and price for roaming services indicates the lack of competition.[197]

[197] Commission Staff Working Paper, Impact Assessment of policy options in relation to the Commission's review of the functioning of Regulation (EC) No 544/2009 of the European Parliament and of the Council of 18 June 2009 on roaming on public mobile telephone networks within the Community, SEC(2011) 870 final, 7 July 201, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2011:0870:FIN:EN:PDF

Moreover, national disparities in retail prices for international data roaming services are large enough to hinder the formation of the single market.

### 3.8.2 Voice roaming stays expensive

Before the 2007 "Roaming Regulation"[198] international roaming charges were far higher than the real costs of service provision and the retail prices of equivalent domestic services.[199] The 2007 regulation set price caps on international voice roaming services. As a result, between 2007 and 2009, revenues for voice roaming fell "quite significantly", even though network operators widened their profit margins on voice roaming rather than passing through to subscribers all the reduction in wholesale prices: "the difference between wholesale and retail prices has risen from 49% in Q2 2007 to 81% in Q2 2010".[200] Regulation (EC) No 544/2009 extended the duration of the original Roaming Regulation to 30 June 2012, broadened its scope to cover wholesale and retail prices for international SMS services[201] and provided for a stepwise reduction of wholesale prices for international data roaming.

### 3.8.3 Data roaming – bill shock still reigns

Even though "forty percent of roamers switch off their data connections when abroad for fear of 'bill shock'",[202] it was decided that retail price regulations for international data roaming should not be imposed before July 2012 as the market was still "emerging" and competitive forces might yet provide adequate discipline.[203] However, BEREC and the Commission staff found that "between Q2 2009 and Q2 2010 (so in the first year of application of wholesale data roaming price caps), wholesale prices have decreased by about 70%, whereas retail prices decreased …about 15%".[204] In other words, as with voice roaming, some operators used the drop in wholesale prices for data roaming to expand their profit margins rather than passing the savings through to subscribers.[205] According to the Commission staff, retail prices for international data roaming services in the EU are still 25-35 times greater than the domestic prices for equivalent services and are not justified by the real costs of service provision.[206] Therefore, in considering amendments for the Roaming Regulation in 2012, the Commission is looking at "structural measures" to increase competition, as well as low cost substitutes for roaming services to put

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[198] Regulation (EC) No 717/2007 of the European Parliament and of the Council of 27 June 2007 on roaming on public mobile telephone networks within the Community and amending Directive 2002/21/EC, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:171:0032:0032:EN:PDF

[199] DG Internal Policies of the Union (2007), Technical Issues on Roaming: Transparency, Technical Aspects and Data Overview related to the Proposed Regulation on Roaming, http://www.europarl.europa.eu/document/activities/cont/201109/20110906ATT26027/20110906ATT26027EN.pdf

[200] Commission Staff Working Paper, op cit, Ref 198.

[201] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:167:0012:0023:EN:PDF

[202] Reiffer, G. (2011), The Ripple Effect of Roaming Regulation, MACH Insights, 24 October, http://machinsights.wordpress.com/2011/10/24/the-ripple-effect-of-roaming-regulation/

[203] Regulation 544/2009

[204] Commission Staff Working Paper, op cit, Ref 198.

[205] BEREC Analysis of the European Commission's Proposal for a Regulation on Roaming COM(2011)402 of 6 July 2011, http://www.erg.eu.int/doc/berec/bor_11_46.pdf

[206] Commission Staff Working Paper, op cit, Ref 198.

downward pressure on mobile roaming charges.[207] Is more Wi-Fi the answer? A 2010 EC study on competition problems in roaming found that the "use of WiFi (ie wireless hot spots) to provide Internet access and Voice over IP (VoIP) was felt by most respondents [to a roaming survey] to be the most practical all-around substitute".[208] So if:

- Wi-Fi access becomes more widespread geographically,
- the process of obtaining and paying for temporary Wi-Fi access becomes less complex and costly, or less necessary (as free Wi-Fi spreads),
- Wi-Fi access becomes "truly mobile" (ie, commonly available in moving vehicles), and
- LTE roaming becomes problematic due to unharmonized band use and spotty coverage in the early years of deployment,

then Wi-Fi will become a more attractive and effective substitute for mobile data roaming and VoIP, exerting downward pressures on roaming charges. Consider that

- the Wireless Broadband Alliance expects public Wi-Fi hotspots to increase from 1.3 million in 2011 to 5.8 million by 2015 (Informa/WBA, 2011).
- Wi-Fi access on trains, buses, taxis, airplanes and in transport terminals is spreading.[209]
- industry efforts to streamline and automate handoffs from cellular to Wi-Fi will soon reach fruition.
- LTE roaming is likely to be more technically constrained than with GSM and UMTS, due to the lack of harmonized spectrum for evolving cellular mobile networks towards IMT-Advanced. Wi-Fi fills the gap.

Hence, increased competition from shared spectrum access networks is likely to help drive down the retail prices of cellular roaming services. However, regulatory vigilance is needed because MNOs are rapidly expanding their involvement in the development of public "hotspot" networks. They have an interest in maintaining roaming profits, perhaps by imposing limitations on handoffs and rights of use, or by preselecting networks which are not challenging cellular services. Competition between roaming services and Wi-Fi may also be thwarted if MNOs can control handoffs and raise the price of Wi-Fi access.

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[207] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the interim report on the state of development of roaming services within the Community, COM(2010) 356 final, 29 June 2010, http://ec.europa.eu/information_society/activities/roaming/docs/interim_report2010.pdf

[208] Marcus, J. S., and Philbeck, I. (2010), Competition Problems in the EU Roaming Market, SMART 2010/0018, WIK-Consult, page iii, http://ec.europa.eu/information_society/activities/roaming/docs/cons11/wik_report_final.pdf,

[209] Smith, G. (2009), Hands out for the hotspot as taxis start offering Wi-Fi access for passengers, Irish Times, 7 July, http://www.irishtimes.com/newspaper/finance/2009/0710/1224250386122.html; Baker, J. (2010) The Connected Train Comes of Age, MuniWireless, 7 June, http://www.muniwireless.com/2010/06/07/the-connected-train-comes-of-age/; Baker, J. (2011), The Cloud – stormy weather for transit wireless? TransportXtra, 22 August, http://www.transportxtra.com/magazines/new_transit/news/?id=27671; Bryan, K. (2011) List of European Airports Offering Free WiFi to Travellers, Europe a la Carte, http://www.europealacarte.co.uk/blog/2011/04/25/european-airports-free-wifi/; Swann, A. (2011) New Wi-Fi tech for the Paris underground, 19 December, Computer Business Review, http://itservices.cbronline.com/news/new-wifi-tech-for-the-paris-underground-191211; etc.

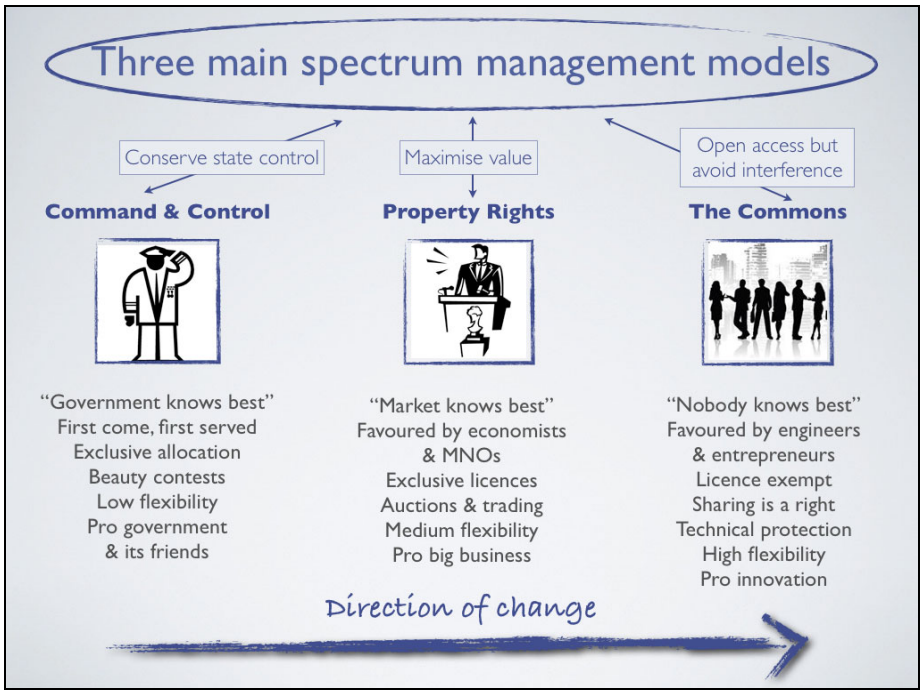
## 3.9. The evolving role of the regulator

> *It is sometimes implied that the aim of regulation in the radio industry should be to minimize interference. But this would be wrong. The aim should be to maximize output* (Coase, 1959, p 27).

In this section, we consider how increasing the amount of shared access spectrum could affect regulatory functions and responsibilities. In Chapter 4 (section 4.9), we examine the impact of more shared spectrum access on administrative costs. But first we explore more broadly how the role of the regulator might evolve in light of technological opportunities and socioeconomic pressures.

Over the past 30 years, the regulatory context has been fundamentally transformed. National telecommunication monopolies have been privatized and broken up. Competitive markets and consumer choice have been introduced for most services. Digitization, new delivery platforms and convergence have made the media landscape exciting but unstable. The command and control approach to spectrum management is now recognized as inefficient and a property rights or market-oriented approach is increasingly favoured (see Figure 3.4).

Figure 3.4. Three models of spectrum management




Adam Smith believed that markets are guided by an "invisible hand". A modern economist would be more comfortable with the notion of a collective intelligence emerging from the decisions of multiple actors. However described, this re-orientation towards an "economistic" view of spectrum makes regulators move away from the assumption that "government knows best" in favour of the assumption that "the market knows best". With this shift has come a more flexible and tolerant approach and a more positive attitude towards the business sector.

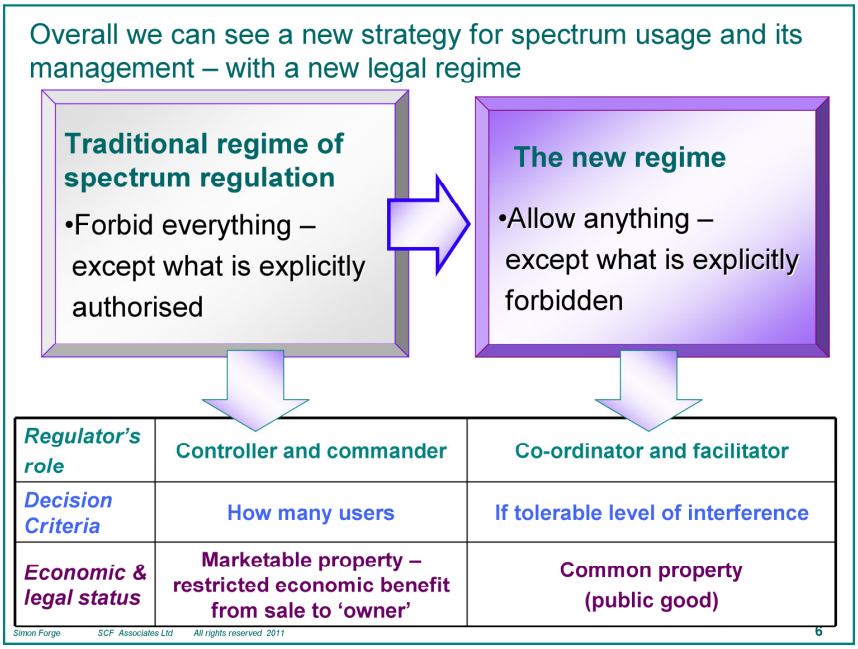
However, the growing importance of spectrum to the economy and society means that the regulator's role must evolve further. In the past the regulator's role resembled that of a policeman, with a focus on the enforcement of technical rules determining spectrum use. What is increasingly needed, however, is a focus on policies to stimulate and exploit innovation while maintaining a balance between competition and cooperation.

Inevitably this will mean moving further away from the command and control approach. This is a trend already well underway. One example is the UK Ministry of Defence's opening of some military frequency bands to new sharing arrangements with others in the public and private sectors. This is part of the UK Government's plan to release 500 MHz of spectrum below 5 GHz by 2020.[210] After the MoD reaches agreement on technical and commercial details with its "customers", it will hand over to Ofcom for authorization.

Shared spectrum access represents a bottom-up approach, as well as a belief that self-interest can make spectrum users behave responsibly. In such a world, regulators will need to rely less on predictability ("regulatory certainty") and become more flexible, creative and strategic in their thinking. The future roles of the regulator will therefore be facilitator, catalyst, and when needed, arbitrator.

In the past the regulator's strategy was to forbid everything that was not authorized. In future the approach must be more tolerant, less authoritarian: allow whatever is not forbidden. This implies a very different role for the regulator, with different decision criteria and a different legal regime (see Figure 3.5).

Figure 3.5. Changing role of the regulator




### 3.9.1 Changing tasks for the regulator

How should a regulatory agency adapt to these new conditions? More precisely, how will the range of tasks NRAs undertake change in the future? These are not simple questions to answer, as there are many unknowns and uncertainties. If we imagine a world in which all spectrum is shared and exempt from licensing, then some tasks currently performed by NRAs would no longer be needed. For instance, spectrum licences would not have to be assigned or renewed, auctions would not have to be arranged and conducted, fewer rules would have to be enforced, fewer rule changes considered.

Similarly there would be new tasks for the regulator. These tasks might include maintaining a public database of spectrum uses and users, monitoring congestion and interference, undertaking compatibility studies, mediating and dispute resolution, and

[210] http://www.mod.uk/DefenceInternet/AboutDefence/WhatWeDo/ScienceandTechnology/Spectrum/

enforcement action against transgressors. Some of these tasks may well be outsourced but would still need coordination and management within the regulatory authority. Moreover, the evolving role of the regulator means that they will likely take on more strategic tasks – a more pro-active planning function to ensure the spectrum is used more efficiently.

There may well be new responsibilities in a world with more flexible spectrum sharing. The characteristics of receivers will become much more important. Issues of standardization, certification of equipment and ensuring equipment conformance should be the responsibility of equipment manufacturers. Nevertheless, this may well entail additional tasks for regulators and internal expertise to ensure that equipment manufacturers are meeting their responsibilities.

Clearly, greater sharing and more licence-exempt use will not mean that regulation and regulators will no longer be needed. As spectrum management evolves, NRAs will inevitably find themselves undergoing a transition in which they continue to do many of their current tasks but at the same time they will do more of the things that go hand-in-hand with greater spectrum sharing. This suggests that, in the short term, there may well be additional burdens on regulators. The shift in emphasis is indicated in Table 3.4.

Table 3.4. Changing mix of tasks for the regulator

| Regulators may do more of these tasks | Regulators may do less of these tasks |
|---|---|
| Strategic planning for economically efficient use of the spectrum | Plan and administer spectrum auctions |
| Monitoring for congestion and interference | Award licences |
| Maintaining spectrum sharing database | Administer licences, collect licence fees |
| Market surveillance | Enforce licence requirements |
| Compatibility studies | |
| Dispute resolution | |
| Enforcement | |
| Planning for spectrum refarming and repurposing | |
| Oversight of equipment regulation | |

### 3.9.2 Readiness to change

Using the most valuable parts of the radio spectrum as efficiently as possible is key to Europe's future economic prosperity. As Europe seeks ways to maximize the return on its radio resources, by escaping from older systems of administration, industry structures and technologies, legislators and regulators need new principles for apportioning spectrum.

The case for a more flexible approach to spectrum management by regulators is compelling, but the change required is quite significant and the difficulties facing regulators should not be underestimated. The telecommunications sector has changed out of all recognition in recent years and regulators have already undergone considerable change in adapting to a newly competitive world.

Viewed in that light, it is not surprising that our survey of NRAs found that, with a few exceptions, the focus is very much on present-day issues rather than future concerns. Nevertheless, the coming spectrum crunch demands that regulators look beyond the immediate concerns and focus more on the future needs of all spectrum users. NRAs have a duty to serve the public and that, we believe, will require them to keep an open mind about the economic and social case in favour of making more spectrum available for shared access. European cooperation will be required if regulators are to embrace the more flexible strategic role that we expect to be necessary in the future.

# CHAPTER 4. Economic and social impacts of shared spectrum: a scenario approach

Having explored the problems with spectrum management and looked at how we can improve spectrum utilization through shared access in previous chapters, we now consider three scenario options. The scenarios capture different amounts and ways of sharing spectrum, principally for wireless broadband. These scenarios are used to modulate an econometric model to illustrate their impacts on the EU economy up to 2020. Overall we form an assessment in both qualitative and, where possible, quantitative terms, of the following areas:

- The net economic benefit of applying shared spectrum access for wireless broadband (and not just the benefits of broadband generally)
- Social impacts of sharing spectrum (again, not just the benefits of broadband generally)
- The cost-benefit impacts of regulation and the various regulatory factors
- Any other impacts – firstly on traditional mobile services like voice and data transmission, in economic and possibly social terms, eg the take-up of roaming services in the light of the availability of shared services – and secondly any other benefits from non-broadband applications that shared access will support

## 4.1. Economic impacts of spectrum – the key factors

Spectrum has become a factor of increasing economic significance over the past two decades. With spectrum applications emerging for uses beyond voice, into fast internet access for HD video (at least 20 Mbps), its economic value will parallel – and may exceed – that of fixed broadband. In the rest of this chapter we try to answer a key question:

*What is the added value of shared spectrum access for wireless broadband?*

We begin by considering the main areas where spectrum, and particularly spectrum sharing, adds economic value. First we need to differentiate between economic effects that may be attributed to different types of telecommunications infrastructure as economic driver:

- Broadband in general, both fixed line and wireless (designated as driver of Type 1).
- Wireless broadband, via licensed spectrum, not shared (Type 2).
- Increased shared access to spectrum, for wireless broadband and non-broadband access (Type 3).

The main areas are defined in Table 4.1 and are classified by these three categories.

Table 4.1. How spectrum can add economic value, with type of infrastructure

| Major areas where spectrum adds economic value | Infrastructure type |
|---|---|
| 1. Productivity at work –increase in productivity owing to wireless connectivity (eg see Maliranta and Rouvinen, 2006). | Type 2 and 3 |
| 2. Infrastructure build – where substitution mechanisms of radio telecommunications can replace the built infrastructure with its transport support (road, rail and air), also offices, supermarkets, car parking, etc (eg by mobile shopping the user can avoid travelling to shop and thus reduce the infrastructure necessary and its build costs). | Type 2 and 3 |
| 3. Internet access for general applications, for the mass of citizens, such as social networking as well as specialized internet usage in professional and leisure activities. | Type 1, 2 and 3 |
| 4. Creation of new industries for both services and products, in a wide range of niche applications, eg ranging from RFID applications in medicine to download of music or videos to smart phones, or banking and payments by smart phone, etc. Note that new shared spectrum based applications introduce an element of innovation to the economy, to create new employment and spur growth, be it in new ventures, or revamping existing business processes, devices or network equipment. | Type 3 (if services, applications, equipment and software are specifically for shared access, else include Type 2) |
| 5. Access to public services, directly dialled to the chosen service or via a wireless internet connection, eg health and education, as well as direct government services for taxation, social security, benefits, for mobile, fixed and nomadic users. | Type 2 and 3 |
| 6. Impacts on existing radio-based services such as mobile cellular – their costs, use of infrastructure and recharging models. This has far reaching consequences if sharing is considered as an opening up of the current industry structure. In particular it challenges the accepted structures today of:<br>▪ Roaming charges in Europe<br>▪ Mobile fees and rate structures, included 'line rental' at a national level<br>▪ Termination rates between operators, both mobile and fixed<br>▪ Charging for newer services such as data, for internet access, as migration to IP-based working in mobile becomes the norm. | Type 3 |
| 7. Other applications outside wireless broadband that have major economic value, eg slow speed monitoring networks for smart electrical grids (which do not need broadband speeds) or intelligent transport (overlaps with 4). | Type 3 |

Although several of these impacts could be delivered by either fixed broadband, or by wireless broadband that does not come from sharing spectrum, in all of the cases above the use of sharing would introduce two potential advantages:

- The creation of additional network capacity for greater connectivity to more users and more types of applications in terms of traffic levels and geographical coverage depending on the form of deployment
- The possibility of lowering the cost of access, such that it is more affordable, ie for more users and more use by each.

Note also that in general the economic power of shared spectrum access is to further leverage the general advantages of mobile communications, ie that it provides '*untethered*' access. This has three attributes for economic advantage. The first two are mobility and ubiquity, which together form the third, instantaneity, or the ability for instant action.

Such economic impacts for shared access must also include any associated costs – in particular for regulators in terms of implementation costs and ongoing administrative burdens arising from opening the spectrum to sharing and maintaining the sharing rules.

In trying to understand the value of shared spectrum, it is helpful to estimate the value of a unit of spectrum in driving the EU economy. However, as we explain below, spectrum

value depends on the frequency band in question. From this it may be possible to go on to consider how one unit of bandwidth corresponds to one unit of GDP or of GDP growth. Thus, the value of 1 MHz at each frequency is different.

### 4.1.1 Impacts of sharing

In considering the sharing model, who would be affected, in what ways and just how such a model could be economically supported are all key questions.

The fundamental criterion for viability of the sharing model is its investment attractiveness. Funding may not always be through the usual sources, of bank loans mixed with large-scale user investments (MNOs, telecommunications equipment suppliers and broadcasters) with funding offset by offerings in the corporate bond market. Factors of social utility, as well as return on investment, are also important, so public funding might also be an option. So how could this be funded?

For the traditional spectrum owners, the MNOs and the broadcasters, sharing spectrum does not appear to be an attractive proposition. In the light of their current business models there is no obvious advantage in sharing spectrum – it just seems to cut through their income streams. However, there are two countering trends that might ensure funding is available, perhaps even bountiful:

1. The appearance of new business models in the mobile and broadcast industries, both associated with wireless broadband but for quite different reasons:
    a. The move to LTE and the need for a communications network that can handle exabytes – Wi-Fi offload appears attractive for the 'last mile' and expanding that through sharing spectrum may be a viable solution.
    b. The rise in awareness in the broadcast industry of web delivery of content and so the need for a ubiquitous broadband network. In future changing channels will be achieved through entering a new web address rather than selecting a new frequency.
2. The 'elephant in the room' – the desire of the computer, consumer electronics and web services (CSCEWS) industries to enter this market. They see the current telecommunications and media industries (not just the broadcasters) as old-style monoliths to be revised, reduced and revamped following the new vertical business models coming from the likes of Apple with followers in Google and Amazon. Apple is particularly interested here, with its next move after iPad tablets into its so far failed efforts into 'smart TVs', Jobs' enduring heritage planned for the next three years.

It is these two groups that could provide the commercial finance but it is the latter, the CSCEWS sector, particularly US-based companies, that has surplus cash to invest.[211]

How might increased spectrum sharing affect EU citizens? The impact is likely to be limited in the first few years, varying in degree, as explored in the scenarios described in this chapter. However, progressively the impacts of sharing that will touch the majority of the EU population would become apparent, in particular:

- Effects on the pricing of current communications services – principally mobile tariffs, especially for roaming and call termination.

[211] Total cash surpluses held by US companies was estimated at $2 trillion in January 2012, an average of 11.3% of assets now in cash, with firms such as Microsoft and Google having over 10% of assets in cash (Demos, T. (2012), 'US groups have $2tn to play with this year', *Financial Times*, http://www.ft.com/cms/s/0/057ea9f4-372d-11e1-b741-00144feabdc0.html#axzz1j3WU9U1c).

- Effects on both fixed and licensed mobile broadband costs and coverage, as competition from shared spectrum carriers, both LSA and LE, for wireless broadband takes off.
- Social benefits owing to widespread take up of radio-based applications, especially wireless broadband, such as those for education, health and social contact.

If sharing were enacted in 2012, signs of change would not be apparent until after 2015 but, by 2020, there would be far more visible consequences for Europe's citizens. The communications and media landscape would be transformed by spectrum sharing with new entrants, business models, styles of radio-based technology uses and applications. A summary of who would be most affected – and how – is shown in Table 4.2.

With consideration of the distribution of costs among the various players and users of shared spectrum comes the notion of a business model for sharing, ie who would need to bear which costs. This would exploit the lowered costs of access to spectrum and speed of access. Evidently there is not just one, but a range of potentially viable business models.

One of the most interesting is the concept already mentioned of community-led networks. This would augment local communications for business and the residential sector, as well as perhaps local emergency services and utilities including mobile services. It would be paid for by the individual customer/users and /or supplemented by local authorities through taxes to encourage business, augment education distribution or provide low cost emergency service communications. Many such networks could amalgamate to form a 'wireless grid' that could compete with and/or augment existing mobile networks and also the fixed local access infrastructure. The general beneficiary would be the user public as well as public institutions.

Another model is the use of Wi-Fi as an extension of the network coverage to support broadband for the roll out of the extension of 3G UMTS, LTE, which will be sold on the basis of its higher data rates than 3G UMTS has achieved.

The equipment changes would be paid for by both suppliers and users. This would require either extensions of current equipment or new equipment. On the supplier side for the MNOs the RAN air-interface equipment would most probably require changes – either replacement or upgrades for new frequencies and perhaps for programmed adaptation to sharing conditions on power, time, geography, etc.

The largest number of units to be upgraded, although not necessarily the most expensive in total, would be on the end-user or customer side. In practice the customer side would require the relevant customer owned equipment – be it handsets, or forms of universal access points such as picocell or femtocell hubs – to be tuneable to the shared frequencies. The extra cost over an existing handset or picocell would be more expensive at the outset and then tend to reduce with time as volume production takes hold. For a home or small business transceiver, the cost could be comparable to existing unit costs in Güifi.net, with its user costs of seventy Euros per home unit, supplying internet access at broadband speeds.

For a handset, additional costs for cognitive radio and SDR extensions with extension of the output range could be of the order of twenty to thirty Euros at the outset.[212] This would include software development costs but prices would reduce with volume production over time.

[212] The bill of materials analysis for modern handsets in mass production gives this order of costs, eg the BOM of the Apple iPhone 4S front-ends, but with all other semiconductors and RAM, is of the order of €46 ($60); "iPhone 4S teardown", *Engineering and Technology*, Vol 6, No 11, December 2011, p 91.

Table 4.2. Effects of more bandwidth from sharing.

| Who would be affected | Impact on business strategy or lifestyles |
|---|---|
| Citizens, urban and suburban users | • Expanded communications choices for mobile and broadband, with white space services – for communications, TV etc<br>• Tariffs lowered by increased competition<br>• Link own Wi-Fi into shared spectrum networks for wireless broadband, possibly with offset tariffs if in a 'FON' mode |
| Citizens, rural users | • Communications at up to broadband data rates, perhaps for the first time, with new mobile and white space services (comms, TV, etc)<br>• Tariffs lowered by increased competition<br>• Link own Wi-Fi into shared spectrum networks for wireless broadband, possibly with offset tariffs if in a 'FON' mode |
| Business users | • Expanded communications choices in all settings<br>• New business oriented services eg radio based machine to machine via WSD – eg for the 'Internet of Things', for logistics, retail, etc |
| MNOs (own licences) | • Competition from new entrants based on shared spectrum, with price challenges for tariffs, roaming charges, termination charges etc.<br>• Receive fees for sharing spectrum, if primary licensor<br>• Competition from new types of entrants – communities, SSOs etc<br>• Use of shared spectrum to build up own Wi-Fi offerings<br>• Roll out wireless broadband services via offload to Wi-Fi on shared spectrum (via LSA, LL or LE) to augment new cellular technologies requiring extra bandwidth eg LTE |
| Broadcast industry: broadcasters (who own licences) to content aggregators and providers | • Opportunity to move into web TV stations and differed content sales, if exploit wider access to lower cost wireless broadband<br>• Lower costs for operations if curtail broadcast SFN operations<br>• Higher competition - lower cost of entry for new entrants, especially for web TV model based on wireless broadband<br>• Emphasis on need to own content for resale over diverse channels to market, so content providers gain market power<br>• If primary sharing licensor, then can receive fees for sharing<br>• TV white space broadcasts expand broadcast channels available |
| Public sector spectrum holders | • Strong pressures from governments to share, for social and budgetary reasons<br>• Opportunity as primary licensor to receives fees for sharing, for relief of budgets under austerity measures |
| New entrants to network services | • Shared spectrum operators (SSOs) could set up business based on secondary licensing and possibly new LE bands for Wi-Fi and aggregations of Wi-Fi type networks into wireless broadband grids<br>• MNOs entering new geographic market territories could set up as SSOs[213], as an alternative to being MVNOs (eg the entrant Chinese MNOs in the EU) |
| Fixed line operators | • Competition from new entrants based on shared spectrum in the local loop<br>• Opportunity to participate in sharing networks, supplying the backhaul for the RAN and also offering a core network package. |
| Emergency & other public services | • New network choices possibly at lower cost, with alternate-routing for backup, either dedicated to each service or based on commercial shared spectrum services for CUG- mode operations |
| Health sector | • Range of new application based on WSD or expanded LE applications, often using simple Wi-Fi (eg cranial sensor or heart monitoring via SRDs or for longer distance)<br>• Expansion of telemedicine with low cost wireless broadband |
| Utilities, etc, public events | • Use of sharing, WSD etc for sensor networks, SRDs etc, for better control of both consumption and distribution network operations |
| Computer, software and consumer electronics industry | • Create and market a range of in-built hardware for business and consumer devices, for applications based on expanded LE spectrum or LSA/LL(eg using simple Wi-Fi technology) or WSD interfaces, generally to expand sales of radio-enabled business and office software applications and downloaded content more generally including simple apps from online stores for all types of media over low-cost/free spectrum<br>• Push to own and control more media content as can supply over the air without the MNOs, so content access, aggregation and distribution are sought for vertical offers |
| Web services | • Major players push into the network services market, using shared spectrum for vertically bundled offers powered by alternatives to user subscriptions. |
| Spectrum for start-ups | • With ease of access to low-cost or free spectrum, new radio-based products and services can flourish |

[213] Operators exploiting shared spectrum, probably exclusively to provide services, eg internet access

Understanding in what proportion who would benefit requires examining the balance between today's spectrum licensees and tomorrow's spectrum users, both on the demand and supply side. The net gain is most likely to be the end-user, in terms of a wider choice of services in increased competitive conditions, perhaps in new clustered aggregations in community networks. Next could be new users of spectrum, SSOs, the entrants from the web, software and computing sector with consumer electronics, who will also drive the semiconductor industry. Also profiting with this would be any innovative supplier, perhaps a start-up in radio technologies, selling either into the CSCEWS sector or direct to end-users or to SSOs, products varying from a plug-in CR front end for existing smart phones to the integrated circuit design for a low-cost Wi-Fi hub with programmable frequencies for sale on the world market to the manufacturers of such devices.

## 4.2. What are the potential social impacts in qualitative terms?

Although the study is primarily concerned with economic impacts, social returns from impacts of sharing are also important. The traditional concern in sharing spectrum is the potential for interference with public service broadcasting (PSB), both TV and radio. In future, however, enormous social benefits are expected to result from ubiquitous access to the internet, which are highly likely to include PSB channels (eg as the BBC's iPlayer service does in the UK). A summary of the main social applications is shown in Table 4.3 (note these may have a direct economic impact as well).

Although such applications could be delivered over fixed line or wireless broadband which is not due to sharing of the spectrum, introduction of more spectrum due to sharing enhances these key applications – in capacity and possibly by reducing costs. The social benefits of sharing are in general to increase availability of those already provided by wireless and internet access, rather than to create new benefits.

Table 4.3. Social impacts of more bandwidth through sharing

| Key applications with social value | Social value |
|---|---|
| Social networking | Medium/high |
| Aspirational value to self (self confidence/ achievement/support) including lifestyle organization, social mobility, gender equality, etc | High |
| Personal safety and security | Very high |
| Entertainment (including PSB) | Medium |
| Education – primary and secondary | High |
| Education – tertiary and through life re-education | Very high |
| Vocational training | High future potential |
| Employment search | High |
| Family cohesion | Medium |
| Support for frail and elderly in the home | High |
| Health and telemedicine | High |
| Convenience services, E-government, mobile shopping | Medium |
| Networks for safety of life - emergency services / others (utilities, transport) | Medium/high |

There is one possible case of new social benefits that may be unique to shared access, especially with licence-exempt bands. This is the potential development of alternative networks, outside the existing commercial mobile radio communications industry, which currently dominates the options for the ordinary citizen. Effectively it is the formation of an infrastructure to deliver applications such as those above through community networks. Such networks may be stimulated by free or cheaper spectrum with either no, or lower, administrative barriers to access.

Thus sharing spectrum also has social impacts for wireless broadband and for lower bit rate networks. Whether new networks based on shared access technologies can be developed into community networks and alternative commercial networks that would compete with MNOs is an interesting question. If such ventures were successful then new operators with shared spectrum access could offer VoIP and video over the internet, and possibly at lower cost than incumbents, and so driving down prices.

In parallel there could also be potential to develop these alternative offerings into public services networks, eg for safety of life, dedicated to emergency services, or for socially valuable services, such as education or health, which would be shared between different institutions to reduce costs to each. Also, those entities with a public service nature, but from the private sector, might share such networks, for instance those from the gas, electricity and water utilities, often requiring slow speed sensor networks for monitoring their operations, especially for smart metering. Special applications, such as intelligent transport systems could also benefit from shared bands, if suitably engineered for safety.

But what forms of delivery and in particular what spectrum demand would these services make? The form of delivery required varies by application, and the application's nature dictates the bandwidth and which part of the spectrum will be most suitable. Table 4.4 explores the characteristics of these applications with social value from a networking viewpoint:.

Table 4.4. Spectrum requirements of high social value applications.

| The key applications with social value | Bandwidth required for characteristics | Form of delivery | Most suitable sharing band |
|---|---|---|---|
| Social networking | Bandwidth for video and /or audio isochronous for live, streaming; download; text | Wireless internet, eg mobile offload with Wi-Fi, or SDR Wi-Fi & xDSL; cellular mobile | Band suitable for any wireless internet, direct or shared, under 1 GHz ; for offloading via Wi-Fi – ie higher ranges (> 5 GHz) for indoor SRDs |
| Aspirational value to self | For full motion video and /or audio isochronous | Mobile or fixed radio access to internet | Wireless internet – under 1 GHz preferred; up to 5 GHz if short range / urban/ Wi-Fi |
| Personal safety and security | Video and audio link | Mobile internet access with IP video | Wireless internet – under 1 GHz |
| Entertainment-commercial TV, PSB, games, etc. | For full motion video and /or audio isochronous | Mobile or fixed radio access to internet | Wireless internet – under 1 GHz; or up to 5 GHz if short range / urban/ Wi-Fi |
| Education – primary and secondary | Video and audio | Mobile or fixed radio access to internet | Wireless internet – under 1 GHz; or up to 5 GHz if short range / urban/ Wi-Fi |
| Education – tertiary and lifelong learning | Video and audio | Mobile or fixed radio access to internet | Wireless internet – under 1GHz - or up to 5GHz if short range / urban/ Wi-Fi |
| Vocational training | Video and audio | Mobile or fixed radio access to internet | Wireless internet – under 1 GHz - or up to 5 GHz if short range / urban/ Wi-Fi |
| Employment search | Internet access, IP video | Mobile internet access | Wireless internet – under 1 GHz - or up to 5 GHz if short range / urban/ Wi-Fi |
| Family cohesion | Internet access, IP video | Fixed or mobile internet access | Wireless internet – under 1GHz - or up to 5GHz if short range / urban/ Wi-Fi |
| Support for frail and elderly in the home | Wide range from monitoring vital signs to video support | Mobile or fixed radio access to internet | Wide range – from EHF for BAN to sub 1GHz for mobile IP video or Wi-Fi |

| | | | |
|---|---|---|---|
| Health and telemedicine | Wide range, from slow speed BAN monitoring in EHF bands to HD video | Mobile or fixed radio access to internet | Wide range – from EHF for BAN to sub 1GHz for mobile IP video or Wi-Fi |
| Convenience services, E-government, mobile shopping | Internet access, possibly IP video | Mobile or fixed radio access to internet | Wireless internet – under 1 GHz - or up to 5 GHz if short range / urban/ Wi-Fi |
| Networks for safety - emergency services, utilities, intelligent transport, etc | Slow speed for utility monitoring only - but full motion video with audio for emergency services | Mobile or fixed radio access, possibly use of internet | Under 1 GHz preferred for range and power - or up to 5 GHz if short range / urban/ Wi-Fi |

**Note**: The main requirement is to access the internet for rich, multimedia services via wireless broadband, including via Wi-Fi as an offload to mobile cellular broadband.

## 4.3. Spectrum value varies according to its physical attributes

The economic value of spectrum varies by its applicability to economic stimulus. This differs widely with the frequency band being considered, from the prime ranges, which have a high prospective economic and social value, down to near to zero, entirely owing to the physical characteristics associated with each frequency band, especially range.

Hence, the value of spectrum can be examined using the following key characteristics:

- Propagation range
- Building penetration (ferro-concrete absorption effects)
- Weather and atmosphere performance
- Digital (bps) capacity at basic carrier rate of 1bps/Hz. (Note that it is unclear how much of a factor this is in reality as it is dependent on DSP techniques, eg LTE advanced protocols claim up to 25 bps/Hz)
- Power efficiency for propagation
- Antenna size

Each of these variables effectively decides what use a particular band can be put to. For instance, some examples of application bands are:

- Lower frequencies (under 100 MHz) – typically for air traffic control, military, and audio entertainment broadcasting
- 0.3 GHz to 1 GHz (lower UHF) , communications over 1 km to 5 km or even 15 km for video, text, voice. This is the 'prime' area, especially valuable between 300 and 700 MHz for wireless internet access, such as downloads.
- Above 10 GHz – directional microwave beams eg at 28 GHz, for backhaul as well as SRDs of all kinds but with ranges from 50m down to 5mm for applications for BANs, RFID, NFC etc.

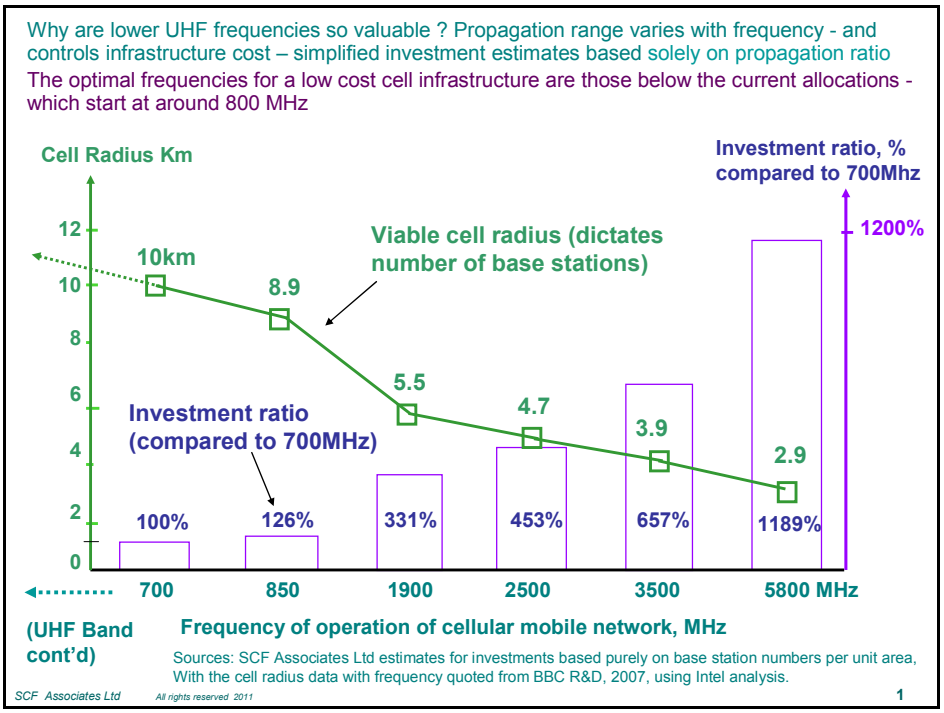
Note that net capacity to serve users is dictated not just by the spectrum range but by the efficiency of protocols that distinguish each user session. These may include various factors, for instance in the mobile cellular model, the number of cells that are employed to exploit geographic multiplexing, plus a number of technology-related parameters such as bps/Hz. The key economic impacts of a band's characteristics are explored in Table 4.5 from the point of view of the physics of signal propagation, which affect quality of service and costs:

Table 4.5. Key parameters for valuing spectrum by frequency characteristics.

| Frequency characteristic | Economic power of characteristic |
|---|---|
| Propagation range | Defines which applications can be used, for what, as well as the infrastructure investment and maintenance costs - and therefore total costs and QoS to the consumer of services |
| Building penetration (ferro-concrete absorption) | Absorption by walls and building structure at higher frequencies is always likely and begins to be seen above 1GHz as more serious attenuation. |
| Weather and atmosphere performance | Absorption of signals by rainfall, water vapour, oxygen bonds, etc is a characteristic of the higher frequencies and EHF, attenuating signals to a non-linear degree. But note that this can be an advantage for SRDs and short range mesh. |
| Digital capacity at basic carrier rate of bps/Hz | Digital bit rate - for raw frequency this increases with frequency, in theory making higher frequencies more attractive for higher bit rates. Modern DSP techniques for compression and signal efficiency have levelling effects, so the difference between 0.3 GHz and 10 Ghz may be largely removed, depending on operating conditions such as ambient signal/noise ratios for high QAM ratios. |
| Power efficiency for propagation | Generally lower frequencies require lower transmitter power for the same distance for the same QoS. This has major environmental impacts in terms of the power consumption, heat dissipation and cooling, losses in power distribution networks and thus the overall GHG footprint, including batteries for handsets. The frequency used may also determine the filter matching characteristics required for optimal transmitted power transfer. For certain more complex, protocols, eg the OFDM propagation for LTE advanced, this becomes important for handset and radio access network infrastructure design and costs. |
| Antenna size needed | The wavelength being transmitted, or received, effects efficiency and design of the handsets and the RAN - generally an inverse relation: size decreases with frequency. |

In terms of infrastructure cost this is shown dramatically in Figure 4.1 – a cellular base station infrastructure for a radio area network at 5.8 GHz requires 12.3 times the capex of one at 700 MHz, due to propagation range and thus cell density.

Figure 4.1. Investments required for a cellular network against frequency.



The quality of signal within buildings, and especially in tree-covered suburbs in heavy rainfall may be a significant attenuating factor for higher frequencies, demanding higher power output from handsets and base stations, with lower battery autonomy compared to a lower operating frequency. Impacts of carrier frequency on cell-size are dramatic. If cell radius shrinks by 50%, to compensate for path loss, then the cell area shrinks to 25% of the previous cell's area,[214] and so at least 300% more base stations are required to cover a given area – at least three times higher investment for operators as well as more energy consumption (over three times due to distribution losses).

### 4.3.1 Spectrum bands have quite different values for the economy

From the above, we can apply some approximate relative weights of the various physical parameters to the economic value of frequency bands. Note, here we are referring not to the supply-side, market value of spectrum at auction under a particular operator's business model but the value to the economy as whole, ie not the profit to an MNO but the increase in the economy's output. These relative ratings reinforce the value of spectrum in the lower segment of the UHF band as being most suitable for long-range, medium and high bit rate applications, such as wireless internet for streaming rich content:

Table 4.6. Valuing the key bands by frequency characteristic.

| Valuation variable | Proportion of spectrum value | Value rating for <1 GHz | Value rating for 1-5GHz | Value rating for >5 GHz |
|---|---|---|---|---|
| Propagation range | 45 - 50% | Hi | Med/lo | Lo |
| Building penetration | 20 - 25% | Hi | Med/lo | Lo |
| Weather and atmosphere performance | 15 - 20% | Hi | Med | Med/ Lo/ V. lo |
| Bit capacity at basic carrier rate of bps/Hz | 5% (may be reduced towards 0% with DSP) | Lo | Med | Hi |
| Power efficiency for propagation | 5-10% | Hi | Lo/Med | Lo |
| Antenna size (minimalized) | 5-10% | Lo | Med/Hi | Hi |

Source: SCF Associates Ltd estimates for commercial infrastructures

From previous investigations (Forge, Blackman and Bohlin, 2007), the relative order of value to the economy in generating GDP growth and employment by the key areas of spectrum may be approximately summarized as:

Table 4.7. Order of magnitude of value of the key bands.

| 100 MHz to 1 GHz | 1 to 5 GHz | >5 GHz |
|---|---|---|
| High economic value between hundreds of billions up to trillions of Euros | Medium – between tens of billions up to low hundreds of billions of Euros | Low - in the hundreds of millions of Euros |

Source: SCF Associates Ltd estimates

For economic stimulus, the sub-1 GHz band is the most value to the EU economy in that it can enable business and services which can contribute to well-being and employment, such as education and health applications.

[214] Square law relation of cell area.

### 4.3.2 Environmental impacts are present but not measurable by value in the scenarios

Note also that although it is not possible to show the social and economic effects in the brief and approximate scenarios constructed here, there are growing environmental impacts of radio services. The intensity of this environmental influence is increasing especially as radio-based packet traffic is expanding so fast, driven by the move to data over the radio-based carriers such as mobile cellular and Wi-Fi. In the next few years, in Western Europe, demand for transmitted data over some form of wireless network (nominally mobile) has been estimated to increase between 2009 and 2014 by 37 times in volume[215], as against traditional transmitted data volume increases of approximately a factor of 10 every 5 years. The latter rate corresponds to an increase of the associated *energy consumption* by approximately 16-20 % per year[216] if accounting for increases in energy efficiency is included. Such energy and GHG impacts tend to increase as the transmission efficiency declines, ie generally with higher frequency, when considering the network node density. In consequence, radio networks of all kinds are an increasing part of the ICT energy budget. The total ICT budget is estimated at between 3% and 6% of total energy consumption and a corresponding percentage of the world-wide $CO_2$ emissions, which is comparable with the airline industry. [217]

Environmental impacts of sharing spectrum for wireless broadband should be largely positive. Effectively wireless broadband could substitute for fixed line broadband. Installation (but not necessarily operation) of wireline for broadband is far more energy intensive due to its civil works. Therefore, overall, greater use of the wireless medium through sharing is a positive step. The main environmental cost-areas for wireline are in building the local access network – the ducts and cable laying for the 'last kilometre' to the subscriber, plus the raw material extraction and refining such as that for copper ores, with plastic sheathing manufacture, also cable manufacture of all types including optical fibre, transport and eventual recycling of cable over its lifecycle. The key question here for the environment is whether wireless broadband will tend to replace fixed, and to what extent this could occur. The extent of fixed line replacement is dependent as much on the commercial market forces from the fixed line side as on pure environmental considerations. Here the forces of promotion, protection of investment in fibre optic and xDSL copper networks will compete with the introduction of wireless broadband, especially for urban areas and suburbs.

Countering the possibility of GHG savings are the environmental impacts of radio networks, eg the batteries for the billions of wireless handset and other recycling of materials, with its recharging budget in energy and greenhouse gases (GHGs), although the environmental costs of fixed line equipment in the home (including Wi-Fi picocell hubs) should be offset against this. A further environmental burden for radio-based communications is the powering of the base stations (or access points for Wi-Fi) with the installation and power consumption of the backhaul network and the core network, which may use part of the national fixed network infrastructure for long distance packet transport.

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[215] Cisco, 2011.

[216] SCF Associate Ltd estimates, assuming an energy efficiency increase of 30% every two years with new network equipment installation made to increase network capacity.

[217] Forge (2007) examines the ICT life cycle in terms of greenhouse gas emissions, power consumption, waste recycling and impacts of operating system change on the environment.

Note that sharing could enable use of the lower UHF frequencies which would lower the density of base stations or access points needed – and so the net carbon footprint and energy consumption for the networked communications. This is important in the scenarios of shared access, in terms of the frequencies available for sharing that could support wireless broadband. In the context of roll-out of LTE with its forecast of high density of base stations, offloading through shared spectrum Wi-Fi could also make an impact on the net carbon footprint of LTE deployment.

Consequently communications network design for environmental sustainability should be performed in a holistic manner. It must look at the balance between fixed broadband and wireless broadband and so may tend to favour radio based services in net social and ultimately economic benefits. This accounting would be made in terms of reduction of total lifecycle energy consumption, carbon footprint and e-waste production over the whole lifecycle, including installation and end-of life processes as well as treatment of consumables such as batteries and the relatively rapid churn rate of handsets.

## 4.4. Proscribed bands: which bands must remain as exclusive allocations?

As we have noted, spectrum sharing is already commonplace in many parts of the spectrum, even in some of the most attractive bands. However, there are evidently certain key bands which should not be shared for reasons of danger to life in hazardous circumstances, where interference could be fatal to aircraft, shipping, emergency services operations, and so on.

Our research has identified the main bands which should not be shared in Europe, as given in Appendix C over the range from 14 kHz to 275 GHz. In particular, between 0.1 GHz and 1.0 GHz, we can identify various bands for distress calls, maritime navigation, air traffic control, etc which must be treated as unshareable. Military uses occur throughout, especially in the higher frequencies above 1 GHz up to 10 GHz, although some bands currently occupied for military use are negotiable, as is the case in the UK. Also in the upper UHF frequencies, there are non-negotiable safety-of-life bands, for aeronautical mobile, maritime mobile and emergency service land mobile bands. Note that there are also some broadcast entertainment bands currently here classed as prohibited but where the future regulation might enable sharing.

This compilation is significant in that it clearly identifies that *sharing is possible in the prime areas below 1 GHz*, currently, as well in many bands up to 10 GHz. The constraining bands to be avoided for safety reasons are all relatively narrow. The impacts on wireless broadband are therefore tangible - in that sharing bands should be positioned to avoid them – but of low impact overall as they are all quite narrow and can be worked around.

This gives a key conclusion on sharing:

> *It is possible in many areas of the spectrum currently under commercial or administrative licensing regimes to use a shared regime without endangering those other services vital to safety of life.*

Such a conclusion is critical for development of new radio technologies for the European economy for the future, putting shared spectrum access at a premium.

## 4.5. Where should bands for sharing be located?

In an ideal world, the choice of which bands should be shared would depend on the characteristics desired for the application (eg video or RFID short-range passive reading) against the available frequencies. Based on our research and consultations, a broad analysis of the most suitable bands for sharing is shown in Table 4.8.

Operators might well prefer to use higher carrier frequencies, for instance in the high multi-GHz range, eg at 20-30 GHz, in order to obtain very high capacity, as potentially a wider spectrum is available. However, only a small range would be covered, and usually only where unobstructed line-of-sight is available. Buildings and rainfall would tend to attenuate signals quickly unless they were directional or reflections were used constructively. So the applications in this range would be rather specialized. Potentially, the band might appeal to a range of operators, for instance the traditional MNOs and fixed line telecommunications operators for short-range extensions, localized community operators (eg shopping malls, office buildings and municipalities) etc.

Table 4.8. Where to share: position, bandwidth, application and value.

| Where in spectrum for shared band | How much bandwidth can be shared | Applications of sharing | Economic Value |
|---|---|---|---|
| Up to 100 MHz | Selected bands with narrow ranges (5 -10MHz), avoiding safety of life services | Ad hoc and specialist eg PMSE | High |
| 100-300 MHz | Minor bands avoiding safety of life services. Highly congested – but highly attractive; use of opportunistic CR possible | Fixed and mobile internet access; wireless broadband possible but unlikely due to limited bandwidth available. | Very High |
| 300- 1 GHz | Highly congested – so little is sharable unless can eventually create a licence-exempt commons (eg from Digital Dividend). May be able to share via TV white spaces | Highly attractive for wireless broadband if get capacity, for Internet of Things types of applications and dynamic access for wireless internet | Very High |
| 1-5 Ghz | Attractive for wider bandwidth applications, if suitable range so cost of infrastructures can be limited | Extensions of Wi-Fi with dynamic sharing and for WiMAX | High/ medium |
| 5-10 GHz | More available for range-limited applications with fairly high power | Specialist SRD eg NFC for mobile transactions to points of sale | Low |
| 10-30 GHz | Highly available for range-limited applications with fairly high power | High power point to point eg microwave backhaul and also specialist SRD networks | Low |
| 30-60 GHz | Highly available for range-limited applications, possibly with fairly high power | Specialist SRD networks eg medical BANs | Low |

In short range configurations, the high carrier frequencies would enable a denser spatial frequency reuse with many nodes (ie with higher capacity per unit area). If multiple hops were used, possibly fewer base station sites might be required, if relays between handsets could carry much of the traffic, demanding a successful mesh-style of network being made to work. In this case, quality of service requirements for short delays (eg for isochronous traffic) could only be met with appropriate equipment and ranges. Such dynamic or opportunistic spectrum management could lead to new business models. But as noted, this could also require a new support infrastructure for dynamic spectrum assignment or trading for spectrum sharing.

We now turn to simulating the effects of sharing through a number of options of the total width of the band shared. Apart from the first scenario, which is a control or *baseline* case, choosing the bandwidth for other scenarios is not as straightforward as one might expect. To select the widths of the bands for each scenario, we first have to ask how much spectrum would be viable and necessary to make an impact on the EU economy. Also, the location of the bands within the spectrum must be chosen carefully so as to have maximum impact on the economy but also to respect which bands must remain as exclusive allocations.

Our design for the scenarios is therefore based on use of Table 4.2, taking into account the analysis of potential allocations, given the costs/benefits of the various frequency bands, and other considerations, including which bands must remain exclusive for safety-of-life.

## 4.6. The approach to estimation

Exploring future visions requires that we put aside traditional thinking and ask 'what-if' questions and then analyse what would be the consequences. To do this, three possible scenario projections, or 'stories about the future', were constructed. They model the potential effects of different degrees of sharing spectrum over the next five years and beyond to 2020. The aim of the estimation technique is to assess in qualitative and, as far as possible, in quantitative terms:

- The net economic benefits of applying shared spectrum access for wireless broadband, and other potential applications. This implies combining the economic stimuli with the following factors.
- The social benefits
- The impacts on traditional mobile services like voice and data transmission including the take-up of roaming services with economic and social benefits.

### 4.6.1 The technique in overview – and its use of three scenarios

With the goal of painting three scenarios of increasing degrees of sharing, a single set of socio-economic conditions was assumed over the period of 2012 to 2020. The only variable was the amount of sharing. Note that all of these scenarios may mix sharing in licensed and *existing* unlicensed bands and may also introduce extra unlicensed bands if required, as in the third scenario, to extend the range of possible sharing conditions.

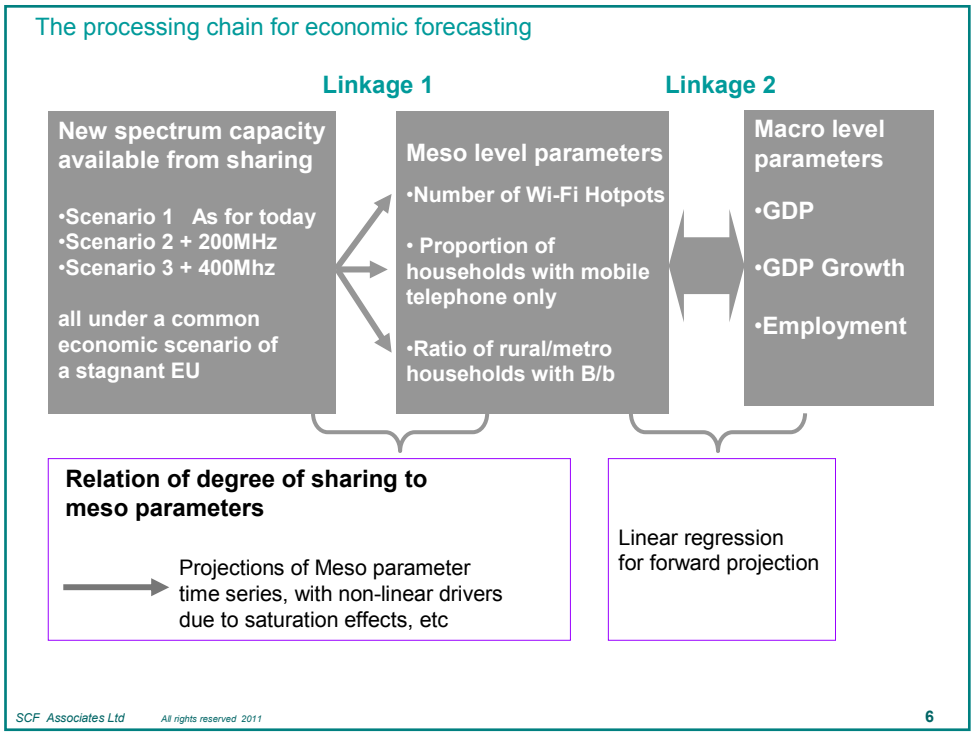
The method rests on the conceptual assumption that it is meaningful to:

a) Link the spectrum available with the behaviour of certain relevant social groups, sectors and industries represented by relevant variables, classed as being at the level of *meso*-economic parameters, such as the spread of pertinent radio technologies (eg Wi-Fi)

b) Link behaviours at the meso-economic level of social groups, etc to national and super-national aggregate variables, such as GDP growth, at the macro-economic level.

This also presumes an acceptance that, although such relationships may be quite complex – as they are non-linear, can be bi-directional in impacts and may have time lags and so may not be in phase – they can be estimated and that such an approach for quantitative evaluation is viable. Figure 4.2 sets out how the various drivers and parameters in the study are interlinked across the two levels of aggregation:

Figure 4.2. The overall estimation approach in outline.




The link from the amount of shared spectrum to the chosen related meso economic variables can be assessed through weighting the forward projection of meso parameters. The assumption is that the capacity and affordability of wireless communications available, in this case added to via sharing, has an effect on them. These projections may then be further linked to macro-economic parameters. The weighting of meso parameters is determined by examination of the conditions of growth of the relevant meso parameters that can be expected from the amount of spectrum available and checking this back against their growth impacts on macro parameters, using measures of broadband effects on economic growth. Effectively, there is a feedback loop between macro-level effects that are reasonable and the related behaviour at the meso level that can act as a check.

Hence the quantitative estimation process uses two stages of linkages, first from the degree of sharing to the meso-economic behaviour and, second, from the meso level to the macro-economic level. The latter employs simple linear regression between the historical time series, for suitable time periods. Note that there is a limit on the accuracy of such methods, depending on:

- The strength and forms of relationships between the different levels of parameters
- Assumptions made on relationships and their behaviour between the parameters with the effects of sharing spectrum
- The quality of data and in particular the length of the time series
- The importance of random perturbations that may distort the assumptions of smoothed development used here.

This indicates the margin of error that can be attributed to results as between plus or minus 50%. Moreover, relationships between the levels of economic aggregation may have

time lags and can be bi-directional, which should be included where applicable. However there are also feedback effects that can be exploited, and may act as a second approach, to give a form of check on the estimations made.

### 4.6.2 Key assumptions in selecting the base conditions for the scenarios

In choosing the scenarios, some major assumptions were made in order to set certain conditions at the outset:

- The most basic assumption was that increasing the bandwidth available for sharing would vary the economic impact, with some form of monotonic relationship, ie that increased shared bandwidth meant increased economic and social effects and that these would be beneficial to European society, although the relationships might not be linear, eg due to saturation[218] of available capacity.
- To define the three scenarios, at the outset, an arbitrary choice was made of the degree of sharing, compared to the first baseline scenario, used for comparison which had zero shared spectrum. In the second scenario, an arbitrary choice was made of 200 MHz to be shared and in the third scenario, 400 MHz to be shared which included 100 MHz of licence-exempt swathes. Why were these particular arbitrary choices made? In reality they are not quite so random or arbitrary as may appear. Initial inspection of the types of applications that could impact the economy materially indicated that for communications to support applications such as business working, education, health, emergency services etc, certain bandwidth minima and spectrum position are necessary, ie there is a threshold of viability for many services to work in parallel for an economically significant size of user community. To make a tangible difference, the lower threshold for sharing over the whole of the EU should enable applications such as file download at 2 to 20+ Mbps and video streaming at 10 to 20+ Mbps, as well as simple VoIP and isochronous IP streams, eg for business videoconferencing or high resolution live video and images for telemedicine. The absolute minimum in total is perhaps fifty to a hundred megahertz of bandwidth, with 'reasonable' portions at suitable bandwidth frequencies. Also the minimum of 200 MHz would compensate to some extent for the allotment for sharing of many bands which are not only scattered but also narrow in bandwidth. Thus a first scenario with two hundred megahertz should easily be viable for accommodating many different types of applications simultaneously for a large enough user population. Moreover there are technical possibilities of combining many narrow dispersed channels in to one logical channel. This could give shared bandwidth for higher data rates and robust operations from the fragmented and dispersed narrow channels. They could be dynamically assigned, to provide an aggregated wider band[219] via dynamic spectrum access for services such as wireless broadband.

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[218] By saturation we imply that the available spectrum capacity is exceeded by the demands for access to services, likely with the growth of data traffic for internet access, so that traffic flows and their benefits limit at a certain point.

[219] Such practice is not new, especially in military applications. It is now being applied to Wi-Fi, in a quest for higher data rates, leading to development of standards that employ multiple narrow channels for efficient and fair spectrum utilisation. Hence Microsoft Research is proposing a new standard, WiFi-NC. Implemented on a software defined radio platform, its novel design enables a compound radio, a single wideband radio, to harness multiple narrow channel radios, each with its own independent transmission, reception and carrier sensing capabilities, suitable for use in white spaces where free spectrum may be fragmented. Chintalapudi, K., et al, *WiFi-NC: WiFi Over Narrow Channels*, Microsoft Research, to be published April 2012, http://research.microsoft.com/apps/pubs/default.aspx?id=157192

- Note that how many (extra) users could be accommodated varies with the type of sharing and the conditions set out in the sharing agreement. These may limit temporal use, range and coverage area, power, etc. So a further assumption is made – that despite these constraints, which are imposed possibly by some form of secondary licensing, tangible economic and social impacts can be realized. This further assumes that competitive behaviour will not be stifled by the nature of the licence being for a secondary user, who might viewed as a threat to the primary licence holder's income stream.
- Thus taking this much further, in Scenario 3, 400 MHz is shared in total. The assumption is also made that this includes two LE bands, each of near 50 MHz, at UHF frequencies both below and above 1 GHz. Such LE bands should enable a large Wi-Fi network or a network with other protocols suitable for unlicensed operations (eg based on WiMAX or possibly LTE technologies). The intention of admitting LE bands is to consider a wider scope of possibilities for modes of sharing, as well as accepting the general notion that a move to more unlicensed spectrum is the future for Europe. Thus the 300MHz of shared spectrum may be used to augment the major LE band capacity (for offloading LTE wireless broadband) and would supplement it for providing other applications, not necessarily for the communications or broadcast industries from other spectrum users who have tended to be excluded (utilities, transport, medical, combined emergency services, etc).

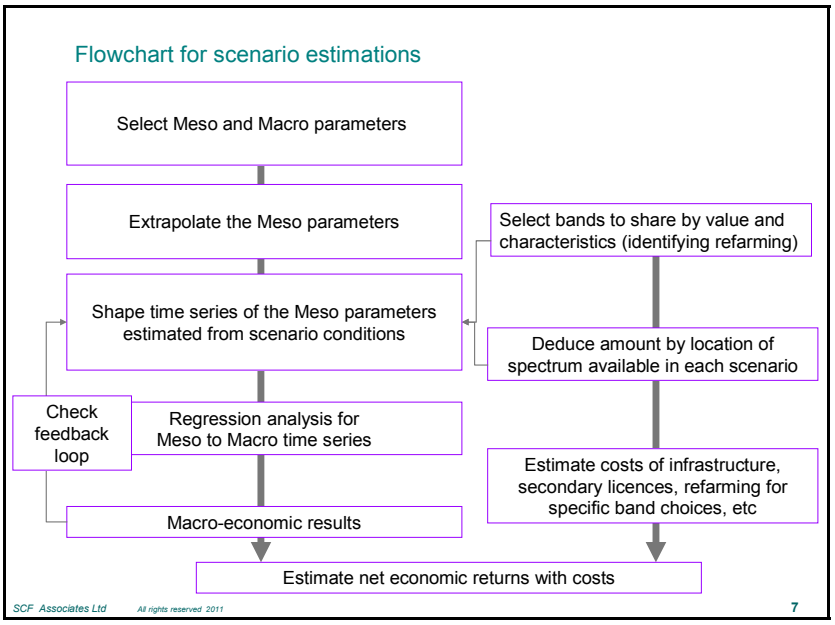
### 4.6.3 The steps in the estimation approach

Consequently, the approach is as follows:

- To assess the net economic benefit, the first scenario will need to establish a baseline, as an extrapolation of today based on "business as usual" against which the two others may be compared.
- Two further scenarios can then show the effects of progressively increasing the degrees of sharing to thresholds which are significant in terms of effectively adding new spectrum. This also implies trying to understand the potential future applications and so what is 'useful and meaningful' for a particular swathe of bandwidth in economic and social impact terms.
- The scenarios can also be used to look *qualitatively* at social impacts and potential shaping of future business models founded on new basic conditions, such as greater spectrum freedoms and novel but appropriate technology, as well as the impacts on traditional mobile services.

The estimation process for the scenarios has the following sequence of steps:

Figure 4.3. Steps in the estimation process.




Effectively there are two streams of processing. The first is concerned with selecting the parameters and their processing. In parallel, it is necessary to examine the width and position of spectrum bands to be used for sharing, with their potential value in economic terms as contributors to the overall EU economy. This implies some understanding of the applications that are suitable for them. In summary:

- First, founded on the premise of sharing as the basic driver of the scenario, the selection of appropriate meso and macro parameters is made. This also uses as selection criteria the quality of data available and its relevance to the problem in hand.
- The bands that are open to sharing are also identified. Reference is made to the existing users (eg by using the European Common Allocations Table[220]).
- The shared bands for each scenario are summed to give the total bandwidth in MHz for each of the non base-line scenarios.
- The shared bands' relative values and suitability for the various types of applications can also be identified. Accompanying this is identification of their function, in terms of their suitability for each type of application (eg non-SRD and isochronous), also using the overarching premise of their ability to make a contribution to the European economy. One approach to identifying what could be useful spectrum to be shared is to examine the various types of radio–based applications, with a set of the main application categories being a 'basket' of applications. Candidates may be selected by their relative value to the economy. The use of application 'baskets' oriented towards wireless broadband with 'super-group' categories may also be useful, in considering how spectrum could be employed, such as:
    - Communications and enabling services (ie those used within other applications and in standalone)
    - Business services, including e-commerce based trading, B2B and public sector services

[220] CEPT Report 025, 2009, from the ERO website.

  - Entertainment
  - Lifestyle support including consumer services such as social networking, shopping, banking and citizen level government support services, such as education, etc

- The next step is to drive each of the meso parameters by the shared spectrum available in the scenario. Sharing has two general influences on the meso parameters in economic terms and social terms. The first influence assumes an increased availability of all those services provided over radio bearers in terms of capacity and coverage which are open to expansion due to shared spectrum. The second influence is the impact on costs or affordability to the consumer of such services and connectivity in general. Overall five possible variables that could be influenced by some degree of sharing (not all may apply, depending on the conditions of deployment) can be identified, which will influence all meso-economic parameters related to the wireless market:
  - Cost reduction due to sharing
  - Increased capacity for more users – with its network effects of more users
  - Increased demand for applications
  - Increased or enhanced geographical coverage
  - Increased data rates

  Together the variables form 'Linkage 1' which is the net impact of spectrum sharing at the meso-economic level parameters. Here, it is assumed that in each case the level of impact of each of these variables on the meso parameters will be set at the minimum value that will cause observable change. Furthermore, it is assumed that use of minimum values should apply to all meso parameters. This is taking the principle of estimating minimum effects and returns of sharing on all the meso parameters is the rational course in a set of conditions where forecasting is so difficult. Moreover it is assumed that sharing effects should be slowly progressive with time and amount of sharing, to give an increasing impact on the time series for the projected meso variable as the impacts take hold up to 2020, rather than a sudden step change effect. We also assume this may be a direct effect even if small but will be non-linear due to various effects in each scenario, eg saturation effects (as defined above) with high bandwidth demands such as internet video.

- Next, estimates are made of the future values of the meso parameters using the influence of the appropriate degree of sharing for the scenario with a shaped development over the period 2012 to 2020 limited to the realistically significant impact curve.

- The final step in the economic benefits processing is to generate the macro parameter values, using the second linkage so the meso parameters drive the macro parameters using linear regression for forward projection. The overall value of the macro parameter is taken as the average of the meso parameter correlation trends, for the 'well behaved' results, by inspection. This is currently necessary in view of the recent uncertainty in the macro-economic parameters' time series. It must be augmented by inspection and selection of the most credible parameter-pair results, as the recent confusion in the European economy makes projections more hazardous and can produce unlikely outcomes. Regression analysis between the meso economic parameters and the macro economic parameters is a valid exercise. It is also valid for

time series in the conditions of time shifting owing to the lag in impacts appearing, and also for reverse relationships (macro parameters drive meso in some cases, instead of meso driving macro parameters) and for time series that are selected for their 'well-behaved' character, ie before the catastrophic economic meltdown of 2008/9 which produced highly volatile time series with a random element. Moreover, it is assumed that the impacts of sharing on meso parameters can be observed, through these regression relationships, on the macro-economic parameters. Costs should be analysed for sharing in each scenario. These include three major items for the significant sharing scenarios which are all highly variable in range of possible value:

  - Infrastructure, including spending by operators and end-users;
  - Refarming costs to move incumbents, where applicable;
  - Administrative costs for monitoring, types test etc (examined in detail in section 4.9)

- Finally the overall net benefits of economic gains against the costs of sharing can be estimated.

### 4.6.4 The relevant meso and macro parameters

Parameters are chosen for their availability as a past time series, their relevance to the impacts of spectrum on the economy and completeness. The meso parameters time series, with reasons for their choice are as follows:

| Meso-economic parameter | Reason for choice |
|---|---|
| EU-27 Wi-Fi Hotspots (source: Jiwire, http://v4.jiwire.com/hotspot-hot-spot-directory-browse-by-country.htm, accessed November 2011) | Tracks growth of both licence-exempt communications and internet access over a radio carrier |
| The proportion of EU-27 households having a mobile telephone access but no fixed telephone access (source: Eurobarometer E-Communications Household surveys) | Tracks dependency on radio-based communications as opposed to fixed line in the EU |
| Ratio of rural and metropolitan households having broadband internet access in the EU-27 (source: Eurobarometer E-Communications Household surveys) | Tracks take-up of broadband generally in the EU ie outside urban centres |

The time series chosen for the macro parameters are:

| Macro-economic parameter | Reason for choice |
|---|---|
| GDP for EU-27 (source: Eurostat) | Tracks gross value of EU economy |
| GDP growth for the EU-27 (source: Eurostat) | Tracks growth rate of the EU economy |
| Employment for the EU-27 (source: Eurostat) | Indicates jobs – proportion of active population in employment |

As noted, compared with the past three decades, the macro-economic parameters above have shown extreme movements over the past five years with the financial meltdown of 2008/9 (the EU GDP growth rate became negative, sinking to – 4.5% in 2009). Such data turbulence makes projections into the next five years and beyond difficult for trend analysis. Thus it is necessary to make the allowances outlined above for this event in order to get some meaningful correlation between the complex pattern of behaviour of macro parameters and the meso parameters, including the effects of time delays before correlated behaviour is observable.

The scenarios assume all the various types of sharing are in use, as presented in the two previous chapters, encompassing the various techniques – administrative, technical, and market-based commercial agreements, including:

- Sub- licensing with commercial arrangements
- Dynamic spectrum access, using power and interference reduction techniques
- Use of white spaces, with cognitive radio.
- Unlicensed spectrum – a commons for licence-exempt devices

## 4.7. The scenario options with results

The objective is to assess through scenarios the net economic benefit of applying shared spectrum access for wireless broadband in both qualitative – and when possible – quantitative terms with an assessment of costs in qualitative and where possible quantitative terms. This should also include the non-broadband radio services as well as the socioeconomic impact on the traditional mobile services, such as voice and data transmission, roaming services, etc. The focus is on the impact over the next 5 years but with the pace of change in spectrum allocations, this may be just the preparation for later years and so results continue to 2020.

These scenarios are constructed using:

- Assumptions, for instance, on the forms of sharing.
- Assertions, for instance, of the effects on potential social benefits.

These assumptions and assertions are used to assemble the conditions for the simulation of net economic benefit both for the projections for assessing the economic benefits of shared spectrum use and for the costs, to give the overall net benefit.

We emphasize that the results from such modelling can indicate no more than approximate trends rather than absolute figures of economic impact. Results should be considered as being within a range of values of error consistent with the degree of approximation of the estimation methods used. A margin of error of +/- 50% applies to both the estimation of the economic benefits and to the forward median projections of the economic variables. This leads to an estimation range of the order of between plus and minus 50% of the median result. The margin of error applies equally to the economic uplift due to sharing and to the median estimates of the future macro-economic parameters. Thus the figures given are the mid-range estimates. Note that in this approach, the impacts of sharing are always taken as having a positive stimulus to the economy, never negative.

### 4.7.1 Assumptions used in all scenarios

The following general assumptions have been used for the three scenarios:

- Enhancing sharing can increase the amount of usable spectrum. This would be the case whether the spectrum is licensed or licence exempt.
- 'New' spectrum, available from sharing, is considered as equivalent to a new economic stimulus. Thus sharing spectrum always adds a positive increment to the major macroeconomic parameters, such as total value of GDP.
- As the full impacts may not be realized within the five year window considered initially, their preliminary effects within five years could set the scene for further benefits, beyond this (ie significant impacts may only be realized in the 2016-2020 timeframe as a result of policy choices made in the immediate future, 2012 to 2015).

## 4.8. Scenario 1: – no change for the better – a baseline scenario

### Theme

The theme is no change in regulation so the scenario just extrapolates the costs/benefits of continuing "business as usual" with emphasis on using what is already permitted.

### Assumptions

- The types of "sharing" used are:
  - Allocations, as now, plus possible increased spectrum use in existing bands that require no regulatory changes
  - More intense use of existing unlicensed bands, for instance more use of Wi-Fi at 5 GHz, as well as 2.4 GHz which becomes saturated
  - Some more light licensing with ASA (already used in France) appearing in more widespread use across the EU where the MNOs agree to share

### Assertions

Here we extrapolate from the assumptions into the key events and conditions that characterize the scenario.

- In later years (beyond 2014) saturation of available spectrum capacity, as previously defined, due to mobile broadband occurs, as little more spectrum is vacant compared to demand – this has severe effects on the radio using industries and eventually on the EU economy.
- The various alleviations possible (without more action to release spectrum for sharing) are nowhere near what is needed. Moreover where spectrum is refarmed from one service to another, the time taken to clear the band and then roll out the new network introduces further significant inefficiencies. For example, there may be some alleviation in some MS if releases occur from 2012 up to 2014/5 of the sub-1 GHz spectrum from the digital switchover, the Digital Dividend. Certain MS may also have spectrum availability by refarming beyond 2012, eg the 2.6 GHz band plus a few additional blocks of spectrum from public sector releases after 2015/2016, eg in the 2.7 GHz to 4 GHz region.
- The only hope to avoid this spectrum capacity saturation is improvements in spectrum efficiency, eg using technologies such as signal compression, better orthogonal encoding, etc, and new more efficient releases of Wi-Fi and WiMAX, possibly with gradual entry of LTE in efficient configurations, as well as SRD technology for use of smaller cells.
- The widening gap between spectrum supply and demand has negative impacts:
  - Data traffic for mobile users is heavily capped, to restrict volume
  - No data roaming in the EU in the timeframe considered
  - Spectrum is sold at constantly higher auction prices, driving up capex demands to operate a mobile business and so mobile charges increase far faster than inflation, especially if large borrowings are called for to fund auction bids.
  - Earlier phase-out of GSM, to make room for the LTE bandwagon, or continued 3G UMTS roll-out so ordinary, poorer voice-only users are forced

to pay higher prices for an LTE infrastructures they never asked for, that may some day offer data they cannot afford

- Potential risks of more interference and poorer QoS
- Roaming and termination charges remain in place and stay high
- Limited free-to-air HDTV

- There is an increasing drive to use Wi-Fi for offload for mobile cellular but this is not enough, even with a move to 5 GHz when the 2.4 GHZ band saturates in dense urban areas, so data saturates. There is an expansion in light licensing to try to increase sharing but it is of little material benefit. In certain MS, pressure on spectrum is likely to become less acute from around 2012 because of a shift from 2G to 3G+ which increases efficiency and data networking availability.
- For this baseline scenario there is likely to be significant pressure on spectrum over the next three to five years as take-up of data services increases before any new network roll out can take place. Until new spectrum and improved network technologies (eg with data compression and new code division such as LTE) become available, this will tend to limit growth of new applications.
- In economic terms, the lack of sharing means spectrum scarcity with minimal positive impacts on GDP parameters compared to other scenarios. As saturation of available capacity due to overloading by data traffic arrives, then the stimulation of GDP growth by radio services of all kinds tails off as mobile broadband stalls as an economic driver or as a stimulant of innovation in new radio technologies.

The key results for this scenario are that the EU economy expands at a minimum rate given by projections from the historic time series. It is not stimulated by sharing and hence there is no bonus from extra spectrum capacity. Thus there is no enhanced communications capability and consequently no new expansion or opportunities and technology platforms, including those of wireless broadband.

### Scenario 1 – in conclusion

The scenario provides a comparison for the sharing potentials of Scenarios 2 and 3. As a baseline, it simply outlines growth due to the normal projection, with no added economic or social factors due to the impacts of sharing. Its theme is no change in regulation – just use what is already permitted only

Incumbent players – broadcasters, MNOs and public services – all tend to retain their holdings and little change is forecast in spectrum management beyond the cycle of auctions for spectrum for new technologies such as LTE.

Some public services may be encouraged to yield some spectrum for licensed services via AIP but generally spectrum 'scarcity' will rise, leading to increasing auction prices, reflected in tariffs for mobile service subscribers. Generally this will precipitate negative impacts for mobile industry, due to widening gap between spectrum supply and demand Expected effects could include tighter data caps on mobile users to restrict volume, earlier phase-out of GSM, potential risks of more interference, etc, as well as broadcast impacts such as no free-to-air HDTV. Rising cellular mobile costs will also constrain users and therefore will impinge on MNO income and revenues.

Little impact can be expected (under current regulation) in terms of net economic benefits from use of shared spectrum access technologies for provision of wireless broadband services. Likewise there will be little effect on the traditional mobile services like voice and

data transmission, apart from higher tariffs, so the charges for call termination, roaming etc will remain in place and will stay high. Roaming data tariffs may even go far higher.

How much wireless broadband will eventually be rolled out thus depends on LTE growth and possible offloading using existing Wi-Fi bands. Expanded use of Wi-Fi in the existing LE band at 5 GHz can be expected especially in zones where 2.4GHz is saturated.

## 4.9. Scenario 2: – Something stirring – modest sharing for alternative light networking

### Theme

The theme is that in this scenario is of expanded spectrum access to provide complementary sharing options to the incumbents' holdings, in a 'light' form. There is an increase in shared spectrum for fixed radio carrier/ nomadic/ mobile users which in some circumstances can reach wireless broadband speeds.

### Assumptions

We assume here that:

- Overall, some 200 MHz is made available via sharing, through ASA/LSA agreements for bands in the public services and commercial sectors, as well as light licensing and other agreements for white spaces with cognitive radio, also short range device (SRD) expansion into the EHF range (already proposed in some MS).
- Scenario 2 will take a level of shared spectrum that can have an impact on the economy at a gross level and so should be significant, with its arbitrarily set level of 200 MHz. Note that there are precedents for this width of swathe (eg the mobile industry in its ASA lobbying).
- This expansion requires certain regulatory actions to encourage sharing.
- There is no refarming of spectrum currently held by incumbents.

The shared bands are as follows:

Table 4.9. Shared bands for Scenario 2.

| *Scenario 2* | | | | Sharing dividend- added value due to new sharing availability | |
|---|---|---|---|---|---|
| **Type of sharing** | **Band position** | **Spectrum width, MHz** | **Value** | **Application class** | **Suitable Application** |
| Existing Wi-Fi bands existing allocations of licence-exempt swathes<br>ASA sharing where already used)<br>Unlicensed bands allocated today | As for Scenario 1 – Existing Wi-Fi bands 2.4 and 5 GHz licence exempt, ASA sharing, unlicensed bands allocated today for ISM, including use of 60GHz (for SRD networks, already licence exempt in some MS) | | | | |
| Broadcast sharing using LSA/ ASA | 55-68 MHz | 13 | High | non-B/B | Monitoring networks, public services |
| | 174-230 MHz broadcasting | 56 | High | B/B | Internet access with business applications; rural services |

| | | | | | |
|---|---|---|---|---|---|
| MNO sharing using LSA/ASA | 862-872 MHz | 10 | High | Non-B/B and B/B pockets | Monitoring networks, public services |
| | 2100- 2120 | 20 | Med* | B/B and SRD | Internet access |
| Military and other public services shared bands- all releases under AIP, for 4 year agreements or longer | 870-872 MHz | 2 | Low | non-B/B | Non-B/B, eg RFID or white space 'keyhole' type applications |
| | 915-917 MHz | 2 | High | non-B/B | Non-B/B, WDSD, etc |
| | 1427 - 1452 MHz | 25 | Med | B/B | Extended broadband - eg Wi-Fi |
| | 2025 - 2060 MHz | 35 | Low/ Med | B/B | Extended broadband - eg Wi-Fi |
| | 4800 - 4825 MHz | 25 | Low | SRD | Medical & industrial, etc SRD |
| | 10 - 10.012 GHz | 12 | | SRD | Medical & industrial, etc SRD |
| Total MHz | | 200 | | | |

* dependent on conditions in sharing contract, which make value less than medium.

### Assertions

Here we extrapolate from the assumptions into the key events and conditions that characterize the scenario:

- The key assertion is that release of even a relatively limited amount of spectrum through sharing agreements with incumbents seeds some pockets of alternative networking. These networks are based on the cheapest, simplest equipment available to offer a local infrastructure with data rates of a few hundred kbps up to 10Mbps. The handsets may be traditional mobile handsets, with a reprogrammed front end for Wi-Fi, or if that is not possible, with an added front end or alternatively a new low cost handset, designed for this market with multiple sharing protocols and a software designed radio (SDR) front-end. Most tablets already have Wi-Fi but other interfaces may added, depending on the radio front end's adaptability.

- This scenario expects the growth of low-cost community wireless with WISPs (wireless internet service providers) becoming more common. An example is Guifi.net, explored in Chapter 3, with 24,300 km of wireless links serving 15,000 households at a cost to each user of around 70 Euros for the customer equipment.

- Such a model can bring social benefits, not just for residential communications at low cost and social networking but also low speed telemedicine care functions such as home monitoring. These very lightweight 'sparse' networks for internet access may also slowly coalesce, using both the fixed network infrastructure and access through the mobile cellular radio-access network. Offering VoIP, internet surfing and interactive teleworking the lightweight wireless networks may suffer from variable quality of service. They are dependent on the frequency bands being used, the conditions in the sharing agreements on power, timing and geography, as well as the range available and features of the locality, such as urban canyons or mountainous terrain.

- Hence regulatory actions required should endorse white spaces, ASA, light licensing, and to replan UHF and EHF. It is also possible that the lower frequencies (VHF, HF, MF) may be involved, as a plan to migrate DTV / DAB etc to cable/satellite/broadband or to use white spaces for restacked DTV channels becomes a realistic option.

- To ensure that all this new network infrastructure creation and operation happens, with the build of an interconnected grid of shared access with primary licensed access, governments help in persuading public services to share their spectrum, especially military, but also for the broadcast and mobile industries.

- Moreover, domestic users of Wi-Fi grouped into FON-style clusters, allow use of their own hubs as access points to broadband networks in return for the use of others' hubs. They may also offer their coverage to the MNOs for broadband wireless coverage in return for payments, perhaps as reduced mobile bills. Thus there is a synergy between MNO frequency sharing and domestic Wi-Fi types cluster networks for wider access to data services – boon to the MNOs in building the LTE offering which early on splits data largely on to the shared spectrum offloads, carrying voice and low-speed data mostly.

- The table of sharing bands above implies that in the near future (2012-2016, with full impact by 2020 or later) new regulation is required for sharing existing bands, with minimal new unlicensed bands being considered. The aim is to garner extra band capacity both below 1 GHz and across all the spectrum by sharing with existing bands. This could bring more spectrum for Wi-Fi like access, more land mobile and cellular, while single frequency networks, SFNs, make more channels available for DTV, more RFID/M2M/telemetering, possibly using TDM with CR techniques for non-continuous operations.

- Sharing mechanisms might range from, for instance, sharing via ASA and light licensing, to white spaces for limited extra broadband access, with white space uses for communications and Machine to machine (internet of things' applications) via Wi-Fi with longer distance but no extension of the current unlicensed bands.

- 'Extreme' mechanisms may be used – for instance forming dynamic channels for a mobile internet service by using what can be accessed from an assortment of shared channels across a wide range of frequencies, on an ad hoc availability basis (ie the carrier switches via Cognitive Radio detection to the next available slot, rather like statistical multiplexers).

- The end-user terminals, mobile type handsets, or transceivers for buildings for point-to-point fixed wireless access, would exploit software defined radios as front-ends to follow frequency changes, opportunistic, directed or pre-programmed, eg for white spaces with cognitive radio type working. For high volume production, the additional software and hardware for such new front-ends could cost of the order of twenty to thirty Euros per handset at introduction, falling to a fraction of that in two or three years, for production volumes are in the hundreds of millions.

- At the upper levels of frequency demand within the home for short range networking for SRDs, could take off with the main applications that will drive traffic, ie largely web browsing, email, gaming, and video streaming. These applications could use existing equipment for each application, with new front-ends to match a local relaying hub – or an added front-end for existing devices.

- For manufacturers of various types of equipment, principally networking for the carriers and network devices for the consumer market (including wireless hubs and also handsets) sharing spectrum provides the opportunities of new markets. But it also introduces novel technical challenges. In particular the WSD market with its CR and SDR demands opens innovative prospects. The options for making equipment suitable for sharing depend on the sharing technology envisaged be it a handset or an access point transceiver, eg it might be based on dynamic spectrum assignment, with cognitive radio to detect potential interference and also a database connected over a pre-set channel. Or is it to be non-dynamic, set to operate in a shared band, following a specific sharing agreement? The first case is obviously likely to be more expensive that the second, although the second could be based on a software defined radio, to set up new frequency and power characteristics for different agreements and thus make it marketable across all frequencies and geographies where different conditions pertain for the various sharing contracts. The costs are high in small volume production, especially to introduce new technology such as that for CR and database query and update. They consist of software development costs, which for a prototype are likely to be on a par with the radio hardware front-end costs. However the picture quickly changes with take-up and volume production for hardware and the increasing returns effects for software, so that in full production equipment costs for carrier quality access points or base-stations would be of the order of tens of thousands of Euros for the upgrade, while a shared spectrum domestic hub may be of the order of fifty to a hundred Euros and the extension to handset some twenty t thirty Euros at the outset, reducing to fraction of that after a few years of mass production.

### Social impacts

This amount of spectrum in the long term can have key social impacts, as illustrated in Table 4.10.

Table 4.10. Social impacts of spectrum sharing for Scenario 2

| Social impacts of more bandwidth (through sharing) - the key applications with social value | Scenario 2 availability |
|---|---|
| Social networking | Major enhancement |
| Aspirational value (self confidence/ achievement/support) | Enhanced |
| Personal safety and security | Increased |
| Entertainment (including Public Services Broadcasting equivalents) | Increased |
| Education - primary and secondary | Enhanced |
| Education - tertiary and through life re-education | Enhanced |
| Vocational training | Enhanced |
| Employment search | Enhanced |
| Family cohesion | Enhanced |
| Support for frail and elderly in the home | Enhanced by monitoring and new applications |
| Health and telemedicine | Enhanced by monitoring and new applications |
| Convenience services, E-government, mobile shopping, etc | Enhanced |

Using relatively low speed wireless networks (0.5 to 10 Mbps) access is provided for job search, socially valuable support services such as education with better affordability and ubiquity than the fixed line broadband access. It becomes an ideal complement to the tablet market and may be supported financially by them where they see an opportunity to lever sales in a particular market, such as the capitals of the EU MS.

### Social and economic impacts on traditional mobile services

There are some useful and positive developments in the wireless market for the consumer in this scenario. Customers see alternatives to traditional mobile locally for internet access over a limited speed wireless connection, approaching broadband speeds. But the cellular mobile industry remains dominant for mobile voice.

However, instead of increased charges and limits on data, as no new spectrum is available, the scenario offers a form of competing infrastructure, even though it is much lighter than the traditional mobile RANs and implemented in local pockets. The introduction of new market forces mean mobile cellular tariffs tend to stabilize then progressively fall with roll-out of the lightweight competitors. Also, auction prices may stabilize or descend, because the large expenditures for spectrum as the ticket to market entry are no longer part of a viable business model. So the bids will be capped by the new reality of shrunken margins and revenue streams, while institutional lenders will be less willing to give generous loan terms and the repayment covenants will be stricter.

LTE will still be the industry goal but its voracious demands for spectrum for data traffic are held in check by the alternative networks, both in competition and in collaboration. Many MNOs can be expected to join forces in some situations with local alternative operators for offloading mobile data traffic, as soon as the entrant wireless networks have the capacity and quality of service. Limited peering agreements for wireless data traffic across MNOs and the community network providers become a market feature.

Effectively spectrum stops actually becoming scarcer in many markets across the EU. But because the sharing is limited, possibilities to relieve all congestion, especially for mobile cellular data for HD video etc, at exabyte levels are quite limited.

Table 4.11. Scenario 2: impacts of sharing on mobile cellular services.

| Traditional mobile services | Impact |
|---|---|
| Voice tariffs | Tariffs tend to stabilize as scarcity recedes and auction prices decrease, while competition from VoIP bites |
| Data charges | Charges stabilize; they may descend where offloads to alternative networks through peering agreements are viable. Offloading saturation via the LE bands for Wi-Fi is relieved in some areas. |
| Roaming | Although cellular roaming charges across the EU still survive due the nature of the alternative networks being in pockets, so that pure VoIP roaming is difficult, these charges decrease and become standardized across all MS for voice and data to provide competition. |
| Termination charges | Reduced where competition from alternative providers is strong |
| Line rental (where applicable) | Generally highly reduced or disappear |

In consequence, even though the alternatives to traditional mobile and direct influences on its pricing are limited in this scenario, spectrum sharing's effect on the market may be assumed to have a leverage effect, touching the majority of users through the rebalancing of tariffs as outlined in the table above.

### Behaviour of the scenario parameters

The general pressures in the scenario are towards relief of stagnation due to saturation, so the scenario parameters' behaviours reflect this condition. However, with the potential for an Exaflood due to mobile data devices (tablets and smart phones in later years after 2015/2016) Europe may still experience saturation of the available spectrum. The economic/ social consequences of this are a lack of economic impetus from wireless use, built into the scenario. Overall, there are median saturation impacts expected on macro-economic parameters, which would initially have a positive growth.

### Impacts of sharing on the DAE targets

Some advance is made towards the DAE targets in pockets of wireless broadband but there is piecemeal coverage of the EU. Hence meeting the DAE targets of 30 Mbps for all households is not possible. Moreover, data rates are likely to be below that mandated and also will quite possibly vary over time with local propagation conditions.

### Results from simulation of economic parameters for wireless broadband

We should note again that the reliability and accuracy of all projections are open to discussion on various counts, including the assumptions declared. The margin of error is estimated at between plus or minus 50% for the figures given, as there are major grounds for inaccuracy in both the uplift due to sharing and the projections of the base macro-economic parameters including:

- The impact of sharing on the meso parameters: the leverage effect of sharing is represented by assuming an increase in overall figures for the forward projected times series over the period 2012 – 2020 (for a total of around 2.5% by 2020 in Scenario 2).
- Sharing's effects on meso parameters are approximated by being taken as equal across all parameters and by taking the minimal degree of change that is practically viable. This is drawn from the breakdown of sharing impacts on the meso parameters into five major areas. A minimal effect is then assumed:

Table 4.12. Impacts of sharing on level of the meso parameters, in Scenario 2

| Scenario 2 | | |
|---|---|---|
| **Meso parameter driver** | **Minimum Impact Amount, % on meso parameter levels of demand, long term** | **Translation into meso parameter demand as % (assumes only 50% of full impact by 2020)** |
| Cost reduction due to sharing | 1 | 0.5 |
| Increased capacity for users and network effects of more users | 1 | 0.5 |
| Increased demand for applications supplied over shared spectrum | 1 | 0.5 |
| Increased or enhanced geographical coverage | 1 | 0.5 |
| Increased data rates generally | 1 | 0.5 |
| Total for 2020 | | 2.5 |

- Accuracy in selecting such a minimalist range, for the increased economic values of the various services made available using shared spectrum, may be strongly questioned on several levels, not only the degree of sharing's amplification of the meso-parameters. The accuracy of the projection of the forward time series of the meso-parameters based on the past series, as well as the continuity of the forward series once shaped, since it assumes no unexpected influences such as random catastrophic events.
- The linkage between the meso and macro variables by regression linearly: there are reverse impacts – ie the correlation may be time-deferred due to 'reverse impacts' of economic prosperity on meso economic parameters – ie the effects of GDP growth are to increase GDP per head and so to drive use of mobile services, broadband take-up etc. Rather than a supply-side affect of increased use of modern technology increasing GDP, we have a demand side effect of prosperity driving take-up. Naturally due to the delays of diffusion effects, this gives a phase

shifted result and so strong correlation with linear regression is only given by using deferred time series. We have used this, but such techniques are open to question.

- Behaviour of the macro-economic time series from the meso economic regression analysis: to try to ensure viable and reasonable results only the time series up to 2008 has been used and this may be questioned, as well as the chances of forward recovery in conditions of continued economic turmoil.

Results for gross EU GDP are difficult to estimate with accuracy and confidence but our simulations for Scenario 2 indicate a surplus over the baseline (Scenario 1), aggregated up to 2020, of a median of several hundred billion Euros.

The estimated value of the impacts of sharing on the EU economy between 2012 and 2020 for Scenario 2 is €302 billion, before costs. Assuming a margin of error of +50% to -50%, this gives a range of additional value to the EU economy of €151-453 billion.

### Costs analysis for Scenario 2

With the introduction of sharing as the basis for operations, a lightweight infrastructure build indicates extra costs for network equipment and devices, but no costs due to refarming spectrum. There are increased administrative costs for NRAs as well as licensee charges for sharing an incumbent user's spectrum, in handling the secondary licensing. The latter are the recurring (annual) costs associated with the licence agreements and their set up. A number of assumptions are made in building this simplified cost model:

Table 4.13. Costs estimates for Scenario 2, for the main cost items

| Cost items | Nature of costs | Order of magnitude (estimates) |
|---|---|---|
| Infrastructure costs | Equipment for networking, including universal access points, support equipment and backhaul<br>End-user equipment including transceiver hubs and terminal devices | €11-12 billion with opex to 2020(see table below and discussion) |
| Sharing costs for licensees and licence holders | Cost in payments by licensees to licence holders | Between €30k/year per MHz and €1.5 m/year per MHz depending on population reached, location of spectrum,[221] etc. At the maximum rate here, for all the 200 MHz this would of the order of €300 m/year ie €2.7 billion up to 2020. Taking this figure for six MS[222] as an averaged gross sum for the EU would put this as €16.2 billion. |
| | Costs in negotiating for licence holders and licensees for each side | €5-10k/day |
| Refarming costs | None – as no costs associated with switching incumbents to new frequency bands. | 0 |

[221] Based on published charges by UK Ministry of Defence, November 2011 and broadcast costings, from value to broadcasters in Aegis, IDATE and Indepen, 2004. Note that the UK is cited for these sharing costs, as it has figures available and these are taken as being representative of the median order of costs throughout the EU27.

[222] The assumption is made that the cost figures apply to for the largest EU economy and that to extrapolate that to the whole 27 EU MS it is valid to make an approximation of a factor of six times.

The infrastructure cost elements are shown below:

Table 4.14. Land use and population density for capacity and cell sizing

| Population and land use in EU-27 | Population % EU-27 | Population millions | Land area % EU-27 | Land area million $km^2$ | Population / $km^2$ |
|---|---|---|---|---|---|
| Urban | 40.3 | 201.5 | 9.1 | 0.3922 | 514 |
| Suburban/Intermediate | 35.6 | 178 | 34.9 | 1.5007 | 119 |
| Rural | 24.1 | 120.5 | 56 | 2.408 | 50 |
| *TOTAL* | *100* | *500* | *100* | *4.3009* | |
| Population, EU -27, 01 JAN 2010 | | 501 m (Source Eurostat) | | | |
| Land Area | | 4.3 m $Km^2$ (Source Eurostat) | | | |

Table 4.15. Approximate model for lightweight low cost infrastructure

| **Scenario 2 - Infrastructure Light: lightweight base stations or, additions to existing MNO sites for Wi-Fi or white space technology or other** | | | | |
|---|---|---|---|---|
| | **Radius, km** | **Area, km2** | **No. of cells** | **No. of people per "cell"** |
| Urban "cell" | 2 | 12.6 | 31206 | 6457 |
| Suburban/intermediate | 5 | 78.6 | 19105 | 9317 |
| Rural "cell" | 10 | 314.2 | 7664 | 15723 |
| | **UAP, € k*** | **No. of cells** | **Capex cost, € m** | **No. of coincident sessions /cell** |
| **Basic set up Capex for equip and install** | | | | |
| Urban "cell", with backhaul, etc* | 12 | 31206 | 374 | 323 |
| Suburban/intermediate | 15 | 19105 | 287 | 466 |
| Rural "cell" | 25 | 7664 | 192 | 786 |
| *Total* | | *57975* | *853* | |
| **OPEX cost :** | | | | |
| maintenance 15% Capex | | | 128 | |
| Site costs average €20k/yr, 9 years, €m | | 10436 | | |
| *Total, capex + opex, to 2020, € billion* | | | | *11.4* |

*Minimal estimates (could be much higher for MNO co-location and site services with backhaul in prime sites).

**By household, with 10% active data transmission on average

Note that the above costs analysis concentrates on the main cost items – it does not include the administrative costs of regulation, dealt with in section 4.9.

Overall, net costs associated with infrastructure for Scenario 2 could be significantly higher than business as usual by a factor of several hundred per cent, owing to:

- Increased number of base stations, if the number of users present cannot be supported in each area or cell by a single transceiver or base station
- Increased number of base stations if the traffic sizing, in terms of number of simultaneous active users, is far greater than assumed here, and also that traffic is dominated by individual users rather than households, who may be nomadic/

mobile and increase the numbers of active users to a large extent, randomly, eg for holiday and outdoor events, etc

- Costs assumed for each cell are inadequate in terms of recurrent costs for site rental pa and also backhaul, support services (power, cooling, security), etc

### Scenario 2 – in conclusion

The net beneficial stimulus from sharing to the EU economy is still of the order of several hundred billion Euros, approaching €270 billion, in view of the fact that the summed infrastructure cost and those of commercial rates of secondary licensing up to 2020 are relatively small in comparison.

The scenario provides a sketch of a lightweight network providing both an alternative to the cellular commercial networks and potential for the other users of spectrum such as the utilities, medical, transport sectors, etc that need more freedom to access spectrum.

Its theme is a relatively modest increase in purely shared spectrum with some 200 MHz being opened to sharing, with normal sublicensing, white spaces with cognitive radio, and use of guard bands and also SRD expansion and light licensing. Such sharing implies new regulation is required for this scenario to be realized, for sharing existing bands, but no more than that (ie sharing with LL, LSA white spaces, etc). In the public sector, use of AIP and similar incentive schemes will also be needed.

The real aim is to gain extra band capacity, especially where possible below 1 GHz but also higher up. However, with the Exaflood for mobile data devices (tablets and smart phones in later years after 2015/2016) Europe may experience saturation.

A first opening to sharing stimulates the economy and society, enabling more radio-based services to drive growth and providing social benefits ranging from lower costs, to new services, due to the impacts of what is effectively new spectrum.

As the incumbent players – broadcasters, MNOs and public services – begin to share their holdings, change appears for the first time in a century in spectrum management. The challenge to the mobile industry implies that maintaining tariffs will be difficult in the face of shared services and roaming charges, call termination charges and 'line rental' will all be difficult to maintain. Innovative new entrants can build new products, services and business models based on shared spectrum access.

A key general trend of this scenario is towards relief of stagnation in wireless data growth due to network saturation. Caps on mobile data could also be removed progressively if certain offloading network solutions are followed. However, with the potential for an Exaflood due to mobile data devices (tablets and smart phones in later years after 2015/2016) Europe may still experience saturation of the available spectrum.

Therefore on the DAE targets question, some advance is made towards them but only in pockets of wireless broadband, resulting in a piecemeal coverage of the EU. There is some uncertainty as to whether wireless broadband could provide comprehensive coverage of the EU to meet the DAE target of 30 Mbps for every household within the 2020 timeframe.

Overall, there are median saturation impacts expected on macro-economic parameters, which would initially have a positive growth. Consequences of this are that there is some stimulus but a lack of strong economic impetus from wireless use up to 2020.

## 4.10. Scenario 3: – Sharing takes off – and the economy

### Theme

There is a dramatic increase in spectrum released by sharing for wireless broadband for rich multimedia, reaching full broadband speeds and providing a promise of solutions for the Exabyte flood. Here we have the spectrum for a Europe-wide continuous alternative radio access network, with its appropriate economic benefits, and at an accompanying cost as refarming enters.

### Assumptions

We assume here that:

- The shared bandwidth doubles to 400 MHz with the establishment of 100 MHz of licence-exempt spectrum in two 50 MHz bands, one in the sub-1 GHz block, and a second at 1400 MHz, both usable for wireless broadband directly and for longer range Wi-Fi (or WiMAX) to offload data from the cellular mobile networks.
- This shared spectrum swathe of 400 MHz with its generous licence-exempt bands for technologies such as Wi-Fi, WiMAX and others has significant impacts on the economy at a macro-economic level.
- Refarming of spectrum currently held by incumbents, ie the broadcasters, public services and the mobile industry, is a viable future path for Europe and is rapidly completed as a set of harmonized bands.
- Releases for licence-exempt and for shared spectrum come from agreements with incumbents such as the public services under AIP[223], which are harmonized across the EU-27. The agreements are quickly met due to the dire economic conditions demanding stimulus, which are the background to all the scenarios.
- Perhaps surprisingly, the broadcasters and the MNOs are far more willing to release their licence–held swathes for licence–exempt bands and also for sharing but for quite different reasons. The broadcasters now want wireless broadband on order to offer novel internet entertainment services for new revenue streams as DTT is challenged by this 'unstructured programming' and also to obtain global reach for their content sales. The MNOs want LTE data offload as urgently as possible, as the nascent LTE roll-out is stifled by over demand and poor quality of service, while they also need wireless broadband as soon as possible for internet access as they also move into content sales and away from bit carriage.
- This expansion requires certain specific regulatory actions to encourage sharing, which NRAs perform efficiently at national and EU-harmonized levels.

The licence-exempt and shared bands are shown in Table 4.16.

[223] There are certain implications of AIP use at an EU level. For the scenario, these come down to making various assumptions – specifically that EU MS governments both accept the principal of encouraging their public services to release some or all of their spectrum for sharing and also that there is some co-ordinated, common agreement on which bands to share across the EU. This also implies that NRAs are both aware of the structure and advantages of AIP agreements (eg as promulgated by Ofcom in the UK) and that reasonable conditions for such sharing, preferably on a common EU basis, can be established, for a range of conditions, from the basis of pricing, to length of agreements, limits of geography, filter or block mask specifications, limits on power emitted, timing, interference measures, emergency measures, etc. Such agreements may be easier to reach with the current economic crisis and the demands for austerity in public services, so that the need for additional sources of income to buttress government department budgets may become a determining factor in the decision to share.

Table 4.16. Licence-exempt and shared bands for Scenario 3.

| Scenario 3 | | | | Sharing dividend- added value due to sharing | |
|---|---|---|---|---|---|
| **Type of sharing** | **Band position** | **Spectrum width, MHz** | **Value** | **Application class** | **Suitable Application** |
| Existing Wi-Fi bands existing allocations of licence-exempt swathes | As for Scenario 1 – Existing Wi-Fi bands 2.4 and 5 GHz licence exempt, ASA sharing, unlicensed bands allocated today for ISM, including use of 60GHz (for SRD networks, already licence exempt in some MS) | | | Existing Wi-Fi | Existing |
| ASA sharing (where already used) | | | | Services for MNOs | Existing |
| Unlicensed bands allocated today | | | | Existing ISM apps | Existing |
| Broadcast sharing using LSA/ ASA, military and some bands for SRDs only; white spaces and CR also | 55-68 MHz (Ofcom already plans to auction this land mobile band) | 13 | Low | non-B/B | Monitoring networks for utilities, etc, public services |
| | 75.2 – 87.5MHz | 12.3 | Low | non- B/B | Monitoring networks, public services |
| | 174-230 MHz ex-DAB broadcasting | 56 | Very High | Wireless Broadband | Wireless broadband, internet access with business applications; rural services |
| | 230-240 MHz non-NATO military - a band for radars and jamming exercises | 10 | Very High | Wireless Broadband | Wireless broadband, internet access with business applications; rural services |
| | Guard bands in 490-520 MHz and guard bands in 600-700 MHz | 20 | High | Wireless Broadband | WSD /CR applications: WSDTV, RFID, internet of Things, etc |
| MNO sharing Using LSA/ASA for SRD only and some white spaces with CR in guard bands | 862-872 MHz | 10 | Very High | non-B/B | Rural services, Monitoring networks, public services |
| | 1800- 1830 MHz | 30 | High | Wireless Broadband | Urban wireless broad band |
| | 2100- 2120 MHz | 20 | Med | Wireless Broadband and SRD | Internet access |
| | Guard bands in 800-900 MHz | 20 | Very High | Wireless Broadband | WSD /CR applications: WSDTV, RFID, internet of Things, etc |
| Licence-exempt new bands in Digital Dividend region | 535 - 585 | 50 | Very High | Wireless Broadband | Wireless broadband, eg for LTE offload |
| Licence-exempt new bands in upper UHF | 1442–1492 MHz | 50 | High/Medium | Wireless Broadband | Wireless broadband eg LTE offload |

| | | | | | |
|---|---|---|---|---|---|
| Military and other public services shared bands- all releases under AIP, for 4 year agreements | 870-872 MHz | 2 | Low except for RFID or white space 'keyholes' | non-B/B | Non-B/B, eg RFID or white space 'keyhole' type applications |
| | 915-917 MHz | 2 | Very High | non-B/B | WSD, RFID etc |
| | 1427 - 1452 MHz | 25 | High | Wireless Broadband | Extended broadband - eg Wi-Fi |
| | 2025 - 2070 MHz | 45 | Medium | Wireless Broadband and SRD | Extended broadband - eg Wi-Fi |
| | 4800 - 4825MHz | 25 | Low | SRD | Medical & industrial, etc SRD |
| | 10 - 10.010 GHz | 10 | Low | SRD | Medical & industrial, etc SRD |
| Total MHz | | 400.3 | | | |

### Assertions

Here we extrapolate from the assumptions into the key events and conditions that characterize the scenario.

- The radio infrastructures that are envisaged technically for sharing would mainly be:
    - Either Wi-Fi or WiMAX or other similar technology types in licence-exempt swathes
    - Networking with transmitters that modify their frequency and power characteristics in the presence of other signals with receivers that mirror that profile
    - Those that are permanently already set up to avoid interference with a primary emitter, by means of geographic, temporal or power limitations. This may include SRD networks.
- With its lighter form of alternative infrastructure, compared to traditional cellular, sharing networks would be designed to complement the existing network structures, both cellular mobile and independent Wi-Fi, to cover the major portion of the EU with wireless broadband at low cost.
- Moreover, with a 50 MHz LE band in the sub-1Ghz range, this configuration is ideally placed to provide wireless broadband to the rural countryside with macro cells covering the spaces outside the dense urban conglomerations.
- This contrasts with Scenario 2 in that two bands in the UHF section enable offloading for the mobile industry, as well as providing a new distribution infrastructure to the broadcasters to exploit wireless broadband for TV and audio programming. A band of shared spectrum of 300 MHz expands the opportunities for novel applications and technology over Scenario 2. In Scenario 3, practically all major radio spectrum operators in the EU, be they civilian or military, would expect to participate in shared spectrum agreements by 2020, as exclusive spectrum assignments tend to decline in favour of LE and LSA management of spectrum.
- The opportunity to provide sharing technology for 300 MHz made available with LSA agreements is not lost on innovative start-ups who form in 'shared radio' clusters, eg in Oporto in Portugal, Karlsruhe in Germany, Cambridge in the UK and Sophia Antipolis in France. New start-ups specialize in the cognitive radio technology needed as well as novel database systems for rapid updates on the white space frequencies, new forms of domestic hubs, aiming first at the consumer market. New carrier level

integration technologies for the cellular industry follows from this, including switches for balanced broadband offloading, lower cost caching edge-servers etc.

- For manufacturers of consumer electronics, the move into sharable spectrum 300 MHz wide by using cognitive front-ends (as well as exploiting the two new licence-exempt bands) could not have come at a better time. Internet-connected devices of all kinds are expected to provide part of the drive behind a recovery from the next recession, after 2015-2017, when sharing will be well established across the EU. It will complement low-cost devices (tablets, flat screen white space TVs, ultrabooks, mostly sold for under €100) which are all shared spectrum enabled. They are sold to a consumer base which still has minimal disposable income and is looking for free or very low cost internet access at broadband speeds.
- Consequently, this sharing configuration could be engineered to offer the DAE targets of 30 Mbps for the remaining EU households (about 5% in total and 17.5% of the rural population) who currently cannot connect to a fixed access broadband network. It would alleviate the worst of the Exabyte crunch as its capacity builds. This is in line with the expected next generation of network architecture going towards 2030[224], with the overall network design of the EU being under gradual sea change to a fibre core network for high speed rings with radio tails, all designed for broadband speeds.
- To ensure this happens, and to build an interconnected grid of shared access with primary licensed access, governments would encourage public services to share their spectrum, especially military, but also in the broadcast and mobile industries.
- Domestic users of Wi-Fi group into FON-style clusters, allowing use of their own hubs in return for the use of others. They may also offer their coverage to the MNOs for broadband wireless coverage in return for payments, perhaps as reduced mobile bills. Thus there is a synergy between MNO frequency sharing and domestic Wi-Fi types cluster networks for wider access to data services.
- The minimal costs of such an infrastructure would be much higher than a network light sharing architecture of Scenario 2, being based on modifications to current types of Wi-Fi base stations, for greater range, data rates and QoS, plus various types of network equipment, that can be integrated, be they for picocells for SDR hubs, for example, or other. These could be reduced by integration for sites and backhaul with re-use of appropriate mobile infrastructure (eg base station site co-location – rental sharing, site facilities for power, cooling and backhaul, etc).
- The end-user terminals, mobile type handsets, or transceivers for buildings for point-to-point fixed wireless access, would exploit software defined radios as front-ends to follow frequency changes, opportunistic, directed or pre-programmed, eg for white spaces with cognitive radio type working. For high volume production, the additional software and hardware for such new front-ends could cost of the order of twenty to thirty Euros per handset at introduction, falling to a fraction of that in two or three years, for production volumes are in the hundreds of millions.
- Effectively, spectrum scarcity also recedes with significant sharing and LE bands, so auction prices may plummet as a spectrum licence is no longer the sole ticket to entry to the mobile voice market. The net effect is to diminish the price per MHz of licensed spectrum as its competitive edge for licence holders evaporates.
- The indirect effects on the economy could also be significant, as existing mobile charges would be progressively reduced and succeeded by the VoIP near-zero tariffs

[224] OECD, Paris, 2006, *Infrastructure for 2030, Telecoms, Water, Land Transport and Electricity*

for both voice and video calling. Lower charges would drive increased mobile usage, as a 'perception of freeness' arrives for data roaming. Benefits would result for the EU economy as a whole, as in general, greater use of mobile services enhances the economic efficiency of the firm.

- But Europe does not just use ICTs. Its industries concentrate on producing them. It has already expanded R&D and production of the latest ICTs by creation of several flourishing radio-oriented industries going back to GSM. Today the EU leads in low-power processors for mobile handsets and tablets (eg Apple's A4 and A5 processors are ARM Cortex designs) and is active in a range of related technologies, from the software defined radio in the late 1990s, to white space devices with cognitive radio. Its initiatives for opening up sharing will trigger a range of new innovation, in technologies that share spectrum more intelligently to avoid interference yet offer high bandwidth and quality of service. Thus spectrum sharing directly stimulates the EU's 'innovation economy' with its skills, high technology jobs and exports potential.
- A further consequence is that the mobile industry's business model would move away from simple communications and more in the direction of content delivery and advertising, in order to recoup revenues and margins.

### Social impacts

A more generous amount of spectrum in the long term can have key social impacts, as illustrated in the table below. As well as these economic benefits, greater shared spectrum access would bring social benefits as a higher proportion of EU citizens profit from the information society. Better wireless broadband coverage at affordable prices for communications, internet access with social networking and entertainment should enable the following:

Table 4.17. Social impacts of spectrum sharing

| Social impacts of more bandwidth (through sharing) – the key applications with social value | Scenario 3 availability |
|---|---|
| Social networking | Major enhancement |
| Aspirational value (self confidence/achievement/support) | Major enhancement |
| Personal safety and security | Increased |
| Entertainment (including Public Services Broadcasting equivalents) | Major enhancement |
| Education – primary and secondary | Major enhancement |
| Education – tertiary and through life re-education | Major enhancement |
| Vocational training | Enhanced |
| Employment search | Enhanced |
| Family cohesion | Enhanced |
| Support for frail and elderly in the home | Major enhancement and new applications |
| Health and telemedicine | Enhanced by monitoring and new applications |
| Convenience services, E-government, mobile shopping, etc | Major enhancement |

The key areas of public sector cost, and often gradual failure – principally the services for education, health, pensions, and social support including help for the aged, justice and policing – can be attacked by good management of technology applications. Excellent health services for all EU citizens at lower cost are needed to ensure that there are no EU citizens without world class health cover. Higher data speeds at lower cost mean that the social services benefit, from new applications that a slower speed networking cannot support, eg remote surgery for telemedicine, or job interviews by videoconferencing, or justice systems that use remote working to speed up their processes.

In providing enhanced educational access for new skills, so access is also created to work and commerce at much lower cost. Wireless broadband with its ubiquity will be put to use as an educational support. EU investments in research and in education pay back larger returns if they are diffused, and high access, low cost broadband would be a major catalyst. Using distance learning, major centres of excellence can set up strong training and lifelong learning courses in multiple languages which have been chosen to meet future employment market demands (be it in new chip fabrication techniques, or smart electrical power distribution, medical qualifications, etc). Under these conditions, many more people will be educated and vocationally trained in knowledge work and high technology. Thus far more EU citizens will be in work than today, often in teleworking, supplying their expertise across Europe. Such communication structures assure that the EU remains competitive globally – by advancing the mass of the population to the higher ground in knowledge work in a manner that is affordable to the citizen and the public purse.

### Impacts on traditional mobile services - both social and economic

The major effect of sharing spectrum, broadly speaking, would be to bring increased competition in markets for voice and data. This competition from sharing would be based on provision of *internet* access, not just voice, as wireless broadband is rolled out, offering VoIP and various forms of video services for calling.

For the mobile industry that has grown up with a voice-based model, the move to data which embraces voice as a packet-based isochronous stream, would tend to generally reduce interconnection, termination and international roaming charges, etc. The latter development highlights the overall impact of sharing on existing mobile cellular services – which is to shrink margins and revenues through increased competition due to alternative network access.

These are positive developments for the consumer. Customers will see alternatives to traditional mobile cellular locally, and for fixed line xDSL and fibre cabled connections for internet access. Instead they may choose a wireless connection, either at or approaching broadband speeds.

Note that in some MS the MNOs could also make arrangements with the large Wi-Fi service providers, possibly limiting competition which would have to be monitored. Expanding their current Wi-Fi operations as an alternative commercial strategy for migration to a new business model is a future likely direction for the MNOs in this scenario. But the cellular mobile industry as whole will remain largely intact, if it can sign suitable agreements for Wi-Fi connection for data and VoIP, offering its core networks for backhaul to the internet.

However, it may no longer be the dominant force in mass market radio communications of all kinds, as effectively, spectrum scarcity also recedes. Other operators, community networks and new types of users such as utilities will be present and anxious to claim a right to provision of their spectrum-based services.

Thus the auction prices in the EU could reduce rapidly because a spectrum licence is no longer the sole ticket to entry to the mobile (voice) market. Moreover that market is becoming a data or internet access market with new parameters for the capacity required that the old structure of spectrum management can no longer support. A rethinking of the framework for spectrum management is at hand that will strongly impact the MNO business model.

Despite new technology developments focused on sharing and licence-exempt bands, LTE will still be the traditional mobile industry's next technology goal. Mitigation of its spectrum hunger, to satiate its Exabyte level data traffic demand could be provided by the

alternative sharing networks, again both in competition and in collaboration, if they are allowed to.

It is thus possible that LTE roll-out could be faster with, than without, sharing, as capacity levels for data traffic handling could be met without very dense base station deployment. Sharing the load also implies overall capital demands can be reduced, lightening the level of borrowing required to finance the new LTE networks.

Overall impacts on the traditional mobile cellular industry are summarized in Table 4.18:

Table 4.18. Impacts on traditional mobile cellular services

| Traditional mobile services | Impact |
|---|---|
| Voice tariffs | As competition bites from the near-zero VoIP tariffs of Wi-Fi access in the LE bands, cellular voice tariffs sink considerably. Effectively, spectrum scarcity also recedes, so auction prices reduce rapidly as a spectrum licence is no longer the sole ticket to entry to the mobile voice market. |
| Data charges | Charges stabilize then descend rapidly as offloads to alternative networks become the standard, via the LE bands for Wi-Fi in most areas so direct cellular mobile data traffic shrinks (as voice and video calls migrate to the internet and the WISPs) |
| Roaming | Charges for cellular voice roaming across the EU survive for some years until alternative networks are rolled out by WISPs and others so that pure VoIP roaming is viable across the EU. Data roaming has a similar fate, but earlier as its charges are conventionally so high. |
| Termination & interconnection charges | Reduced where competition from alternative providers is strong and slowly eliminated as new business models evolve |
| Line rental (where applicable) | Generally disappears with competition |

### Behaviour of the scenario parameters

The general pressures in the scenario are towards economic growth as the spectre of spectrum saturation recedes, opening the way to handling an Exaflood of demand for wireless data services as sales of tablets and smart phones expand, especially after 2015/2016 with price drops, more apps and new ways of working with them, as part of knowledge worker's lifestyles. With no mobile data network saturation of the available spectrum, Europe experiences strong growth with its more efficient use of the ether. The economic and social consequences of this are a strong impetus from wireless use, built into the scenario, which has a positive growth to 2020.

Note that as part of economic growth, the impacts on innovation from regression analysis on the meso-economic parameters are difficult to pinpoint. Impacts of new growth due to innovation will tend to be reflected in the general economic success and employment and so are reproduced at the meso level by generally increased demand for applications, increased use of shared spectrum, through new devices, and cost-based demand as innovation in shared spectrum technologies puts new services and devices into the hands of groups of users. The limits are that such analysis can only identify a general trend to greater use of shared spectrum with innovation, but largely only as reflected in demand-side variables.

The impact of sharing on the meso parameters for Scenario 3, is represented by assuming an increase in overall figures for the forward projected times series over the period 2012 – 2020 (for a total of around 5% by 2020 in Scenario 2). Sharing's effects on meso parameters are approximated by being taken as equal across all the parameters and by taking the minimal degree of change that is practically viable. The effects of 100 MHz of LE plus 300 MHz of shared licensed spectrum could be seen to have more than double the impact of sharing in Scenario 2, as various effects such as a threshold of saturation for wireless broadband are less likely. However, to be conservative in estimations, the impacts

of 400 MHz of sharing on the meso parameters are constrained at double the figures for Scenario 2. Impacts are again drawn from the breakdown of sharing impacts on the meso parameters into five major areas. The minimal effect is then assumed:

Table 4.19. Impacts of sharing on level of the meso parameters, in Scenario 3

| Scenario 3 | | |
|---|---|---|
| Meso parameter driver | Minimum Impact Amount, % on meso parameter levels of demand, long term | Translation into meso parameter demand as % (assumes only 50% of full impact by 2020) |
| Cost reduction due to sharing | 2 | 1 |
| Increased capacity for users and network effects of more users | 2 | 1 |
| Increased demand for applications supplied over shared spectrum | 2 | 1 |
| Increased or enhanced geographical coverage | 2 | 1 |
| Increased data rates generally | 2 | 1 |
| Total for 2020 | | 5 |

The margin of error again must vary between plus or minus 50% for the figures given, as there are major factors for potential inaccuracy including:

- Selecting such a minimalist range – this may be strongly questioned, especially sharing's amplification of the meso-parameters. Also the accuracy of the projection of the forward time series of the meso-parameters based on the past series, may be queried as well as the continuity of the forward series once shaped, since it assumes no unexpected influences such as random catastrophic events.
- The linkage between the meso and macro variables by regression linearly: there are reverse impacts, ie the correlation may be time-deferred due to reverse impacts of economic prosperity on meso economic parameters – ie the effects of GDP growth are to increase GDP per head and so to drive use of mobile services, broadband take-up etc. Rather than a supply-side effect of increased use of modern technology increasing GDP, we have a demand side effect of prosperity driving take-up. Naturally due to the delays of diffusion effects, this gives a phase shifted result and so strong correlation with linear regression is only given by using deferred time series. Such techniques are open to question.
- Behaviour of the macro-economic time series from the meso economic regression analysis: to try to ensure viable and reasonable results only the time series up to 2008 has been used and this may be questioned, as well as the chances of forward recovery in conditions of continued economic turmoil.

### Impacts of sharing on the DAE targets

Network capacity, especially in the LE bands means that high capacity networking is likely to be available in much of the EU. Progress can thus be made towards the DAE targets using wireless broadband with large-scale coverage of the EU being possible by 2020. Hence meeting the DAE targets of 30 Mbps for all households is viable but 100% coverage is still a challenge. Data rates are likely to be equal to the targets in many but not all locations and also will quite possibly vary over time with local propagation conditions.

### Results from simulation of economic parameters

Results are difficult to estimate with accuracy and confidence. However, the results for gross GDP for the simulated case aggregated to 2020 indicate a significant economic

stimulus due to sharing for Scenario 3. Against the baseline of Scenario 1, the simulated case indicates an injection of more than eight hundred billion Euros into the EU economy, before costs for a sharing network.

The estimated value of the impacts of sharing on the EU economy between 2012 and 2020 for Scenario 3 is €888 billion, before costs. Assuming a margin of error of +50% to -50%, this gives a range of additional value to the EU economy of €440-13330 billion.

### Costs analysis for Scenario 3

The network architecture is significantly different to the previous scenario, and so are the costs. In Scenario 3, we take advantage of the two significant licence-exempt bands especially to give the cell range required, as well as any other sharing mechanisms that may be appropriate to the spectrum being shared. This leads to a heavier infrastructure of fairly uniform connectivity across the EU, for a Europe-wide continuous alternative radio access network, but at a much higher cost. A number of assumptions are made in building this simplified cost model which are open to inaccuracy.

Infrastructure costs are estimated to be of the order of less than one hundred billion Euros, (some €87 billion, a median within a range of €40-130 billion) but could be less under some circumstances. For instance, there could be higher re-use of some mobile infrastructure (eg base station site co-location – rental sharing, site facilities for power, cooling and backhaul, etc).

In this scenario there are also costs due to refarming spectrum in the two LE bands, as well as those charges for sharing for the secondary licensees, for an incumbent user's spectrum.

Table 4.20. Cost estimates for Scenario 3 for main cost items

| Cost items | Nature of costs | Order of magnitude (estimates) |
|---|---|---|
| Infrastructure costs | Equipment for networking, including universal access points, support equipment and backhaul<br>End-user equipment including transceiver hubs and terminal devices of all kinds including handsets. | €87 billion with opex to 2020 (see table below and discussion) |
| Sharing costs for licensees and licence holders | Cost in payments by licensees to licence holders | Between €30k/year per MHz and €1.5 m/year per MHz depending on population reached, location of spectrum, etc.[225] At the maximum rate here, for all the 300 MHz (excluding the 100 MHz of LE bands) this would of the order of €450 m/year ie €4.05 billion up to 2020. Taking this figure for six MS[226] as an averaged gross sum for the EU would put this as €24.3 billion. |
| | Costs in negotiating for licence holders and licensees for each side | €5-15k/day |
| Refarming costs | Costs associated with switching incumbents and their business to new frequency bands, with loss of business. | This has been taken[227] as €1.8 m/ year per MHz, so up to 2020 for 100 MHz this would be €1.62 billion. €. Taking this figure for 6 MS as an averaged gross sum would put this as €9.6 billion. |

[225] Based on proposed charges by UK Ministry of Defence, November 2011 and broadcast costings, from value to broadcasters in the Ægis, IDATE and Indepen (2004) study.

[226] The assumption is made that the cost figures apply to for the largest EU economy and that to extrapolate that to the whole 27 EU MS, it is valid to make an approximation of a factor of six times.

[227] Based on figures produced by Ægis, IDATE and Indepen (2004).

Other costs are those of the regulatory efforts for administration (see section 4.9 ).Note that the refarming costs are open to discussion. The figure used above is based on a study for Ofcom in 2004 for the value of spectrum to the broadcast industry, valued for switchover between analogue and digital and so could be taken as low, as currently, with digital channels the capacity per MHz is higher. However the effort to switch *digitized* DTT channels to new frequencies is far lower than for the original analogue switchover. Also we have taken the refarming and sharing costs as being extended to all the EU's MS from one major economy (the UK, as it has available figures and these are taken as being representative of the median order of costs throughout the EU27) as being a factor of six. This may be higher or lower and depends on local conditions in each MS.

Moreover the figure of €1.8 m/year/MHz for refarming implies complete loss of that capacity, literally, whereas the nature of refarming is to substitute new spectrum, so costs are centred more on changing frequencies. In the broadcast industry with intelligent transmitters and digital TV receivers, the broadcasters may reprogramme equipment using software defined radio front-ends for new channels, while the viewers' TVs rescan for these channels, manually or automatically. A similar procedure is now the case for the MNOs who can reprogramme a software-controlled base station front-end, while the subscriber handset devices must have the new channel bands activated, plus a suitable transceiver that can automatically adapt. This is the same multi-band switching process that such devices automatically perform on changing country, eg from GSM 900 in the EU to PCS 1900/1800 in the USA, ie for a new mobile regime with preset frequencies.

The infrastructure cost elements are shown below using the same EU-27 land use and population density for capacity and cell sizing as for Scenario 2.

Table 4.21. Approximate cost model for the full infrastructure of Scenario 3

| **Scenario 3 - Full LE infrastructure: Wi-Fi, lightweight base stations, and other technologies with some MNO site sharing** | | | | |
|---|---|---|---|---|
| | **Radius, km** | **Area, $km^2$** | **No. of cells** | **No. of people per "cell"** |
| Urban "cell" | 0.5 | 0.8 | 499300 | 404 |
| Suburban/intermediate | 3 | 28.3 | 53070 | 3354 |
| Rural "cell" | 5 | 78.6 | 30656 | 3931 |
| | **UAP***, € k*** | **No. of cells** | **Capex cost, €m** | **No. of coincident sessions /cell**** |
| **Basic set up Capex for equipment and installation** | | | | |
| Urban "cell", with backhaul, etc** | 15 | 499300 | 7489 | 40 |
| Suburban/intermediate | 30 | 53070 | 1592 | 335 |
| Rural "cell" | 50 | 30656 | 1533 | 393 |
| *Total* | | 583025 | 10614 | |
| **OPEX cost :** | | | | |
| Maintenance 15% of Capex + 10% Amortization, 9 years (equip. deflation) | | | 23882 | |
| Site costs average €10K/yr, 9 years, € m | | 52472 | | |
| *Total, capex + opex, to 2020, € billion* | | | | *87.0* |

*Minimal estimates (could be higher, especially for MNO co-location and site services with backhaul in prime sites).
**By household/user, with 10% active data transmission on average, may be higher
***Note also that the term universal access point (UAP) is used as the exact nature of the sharing or licence-exempt transceiver can vary and may not be comparable to a conventional mobile base station arrangement.

Amortization costs assume that replacement costs are subject to price erosion typical for ICT and networking technology. Note that with the large volume of cell sites, average support costs over the EU-27 have been assumed to be reduced by volume-based agreements so that the opex costs are reduced considerably.

Overall, the infrastructure costs for Scenario 3 could be higher, by a factor of several hundred per cent for the network infrastructure, owing to:

- Increased number of base stations, if the user numbers cannot be supported
- Costs assumed for each cell are inadequate in terms of recurrent costs for site rental pa and also backhaul, support services (power, cooling, security), etc, if volume-based agreements cannot be arranged.

### Scenario 3 – in conclusion

Our simulations show that in the third scenario, the most generous and open scenario for shared access, the *net* increase in value to the European economy, with costs taken into account, was of the order of several hundred billion Euros over nine years – some €776 billion, being a median of between €390 and €11,640 billion assuming a margin of error of between +50% to -50%. This is the net benefit after costs for introducing sharing with existing users.

The scenario also holds the promise of potential coverage at high data rates, approaching the DAE targets of coverage for all EU households with wireless broadband at 30 Mbps.

Here, the theme is that shared spectrum totals 400 MHz, consisting of a mix of sharing existing spectrum and two new licence-exempt allocations – each of around 50 MHz at approximately 500 MHz and 1500Mhz. This offers a dramatic increase in spectrum for wireless broadband for a diverse range of media types. It assumes technical advances eg mesh, new sharing technologies – CR etc.

Hence this final scenario envisages a complete set of novel radio networks, services and players with enormous potential – we are almost '*starting again in radio*'.

It challenges the current incumbents far more fundamentally. But it also offers them far more in a co-operative situation, especially if wireless broadband can be hosted on shared spectrum:

- The MNOs receive offload support for their next technology, LTE, to cope with the Exaflood, so they can churn the market and deliver on the only promise of improvement that LTE really has – of much more data at much faster speeds
- Broadcasters gain a new channel to market for their content and enter the internet world and can partake of the migration in advertising to the Web
- Public services receive budget injections at a time of administrative funding crises

Most importantly, a critical condition for this scenario is that regulation is formulated, perhaps at the next WRC, or even before, for the LE swathes. Further changes in regulation for sharing with LL, white spaces etc will also be required for this scenario to be realized. For the public sector, use of AIP and similar incentive schemes would be needed.

In the scenario, sharing strongly stimulates the European radio and electronics sectors with a new market for WSD and other sharing technology products. It also opens up a range of services opportunities, from white space TV to increased delivery of content over broadband, using wireless carriers. New entrants could range from alternative shared services operators to the current software and web services players, keen to provide vertical offerings via shared spectrum.

The scenario offers the possibility of meeting the DAE targets through a new expansion for Wi-Fi and perhaps the potential for WiMAX in LE bands in the EU, with EU-wide coverage, especially for rural residents. And at high data rates are viable so that 30Mbps could be offered via wireless broadband. But to meet the date of 2020 for this, regulation would have to be quickly formulated and agreed.

Such new sharing would have strong impacts on traditional MNO tariffs and business practices The challenge to the mobile industry implies that maintaining tariffs will be difficult in the face of robust and low-cost shared services such that roaming charges, call termination and 'line rental' will all be difficult to maintain and would be progressively abandoned, as the mobile industry moves towards new business models.

## 4.11. Conclusions on estimating net benefits of additional shared spectrum

Sharing spectrum offers major economic advantages for the EU, as explored above in both qualitative and quantitative terms. Simulation of an expanded use of licence-exempt bands with Scenario 3 indicates that there are major social and economic advantages in opening the spectrum in this way, well beyond light licensing and secondary user mechanisms of licensing, as explored in Scenario 2. Although the costs may be higher, the net economic benefits could outweigh these considerably.

The 'light' model of Scenario 2 shows that there could be significant social and economic benefits in this simpler model. Europe needs such economic stimulation as quickly as possible. So a phased approach of proceeding toward Scenario 2 first, with its pockets of alternative networking which can be later 'joined up' in a far more capital-intensive use of licence-exempt networking is attractive, from a practical and pragmatic point of view of the speed of change in spectrum management and the build-up of new business operations.

However, pursuing Scenario 3, immediately, in the *regulatory process* for its LE bands may pay off in that the release of major swathes of UHF spectrum could take some years. This requires immediate action to agree and earmark the potential bands and begin a re-allocation process.

Persuading the various incumbent holders of spectrum to release their holdings for sharing with others is one major barrier. Considerations of national and European economic and social benefits should persuade governments and the EU to take up a policy to convince these incumbent holders of the need to release their spectrum into a sharable state.

Moreover, going further, with the formation of alternative networks based on citizens and communities networking and co-operating with the private sector (both broadcasters and MNOs) needs to be encouraged by governments, in order to provide wide area wireless networks, built up from these local initiatives combined with domestic ownership of wireless hubs and the MNO networks.

Note that the quantitative results presented here are open to discussion owing to the many intangibles and unknowns for which assumptions have been made. Thus the results in quantitative terms can be taken as approximations only.

## 4.12. The impact of increased sharing on administrative costs

The study has assessed the impact on administrative costs arising from additional spectrum being made available for shared spectrum access. In this context, administrative costs refer to the costs incurred by enterprises, public authorities and citizens in meeting legal obligations to provide information on their action or production, either to public authorities or to private parties. Here, information is defined in a broad sense, ie including labelling, reporting, registration, monitoring and assessment needed to provide the information.

Administrative costs comprise two components: business as usual costs, and administrative burdens. Business as usual costs correspond to the costs resulting from collecting and processing information that would be performed even without a decision to make additional spectrum available for shared use; administrative burden refers to costs specifically linked to information that would not be collected and provided unless there was a legal obligation to do so.

Most NRAs have not yet considered the administrative burden of increased shared spectrum access. In our survey, NRAs expressed divergent views on whether it would bring additional costs or savings to the regulator and whether the amounts would be negligible or significant. In the case of a light-licensed approach, some could see that an improved administrative process and simplified regulation might benefit both regulators and current licence holders. This would occur by making savings in the administrative costs of authorization and, in some cases, the direct costs associated with the auction of spectrum licences. It would be offset, some NRAs thought, by increased coordination costs and costs for interference monitoring. Some NRAs thought increased shared spectrum access would not result in any additional administrative burden.

Similarly, the business sector has not engaged with this question. Existing licence holders are very much focused on future business models rather than administrative costs. There could be a small impact on manufacturers of network equipment and handsets in terms of certification of equipment, although this is thought to be negligible.

There would be no direct impact on citizens, although indirectly a proportion of any additional administrative burden might feed through to them as tax payers, or as end users in the cost of handsets or connection costs. But for the purposes of this study we focus on the more substantive impacts on regulatory authorities.

In the rest of this section we report the results of our research to estimate the administrative burden for regulators arising from increased spectrum sharing. This is a difficult task to do with any degree of accuracy as there many variables and quantification requires many assumptions to be made.

### 4.12.1 Factors affecting administrative costs

Increasing shared spectrum use would have some direct impact on the administrative costs of regulatory authorities and spectrum users. The scale of the impact and the issue of who would be responsible for bearing any additional costs are influenced by a number of factors, including:

- How much spectrum is to be shared, and in which bands
- The number of sharers, the amount of traffic generated and the behaviour of sharers.
- The basis for authorization: a licensed, light-licensed or licence-exempt approach
- The basis for sharing, eg "politeness protocol" v spectrum database, or both.

So, for instance, if sharing were performed using politeness techniques, such as "listen before transmit", this could require additional hardware and software to police a licensed band. If this was allowed on a licence-exempt basis, then these additional infrastructure costs would fall on the unlicensed sharer. Conceivably there could be a negligible impact on administrative costs arising to spectrum users and regulators in these circumstances.

If, however, sharing was carried out by means of a spectrum-sharing database and this would be for the regulator to administer, there would be some additional costs for the regulator to bear. The basis for a spectrum database is comprehensive spectrum monitoring. Regulators could sub-contract the task of spectrum monitoring to a specialist third party and either bear the cost or, in theory, offset these costs by passing some on to other stakeholders. However, in their study for Ofcom, CRFS (2008) was not able to identify any real offsetting revenue opportunities: although there was widespread interest in the data that a monitoring system would provide, there was no willingness on the part of broadcasters, third party spectrum managers or MNOs to pay for it.

We envisage the need for spectrum monitoring regardless of how sharing is done. With less reliance on licensing, the regulator will not know where transmitters are deployed unless they report their location to a database or monitoring detects them. We would hope that the purpose of monitoring would gradually shift from enforcement (catching unlicensed transmitters) to checking on efficient use and planning. It may also be that monitoring will be needed to arbitrate interference disagreements.

So what would spectrum monitoring cost? A conventional, automated monitoring system (AMS), with sensors fixed in urban and rural areas (eg on lamp posts and/or at cell sites) is an expensive solution if extensive geographical coverage is required. A study by Sagentia (Ollerenshaw, Bearpark and Mottram, 2006) for Ofcom estimated the implementation costs for such a scheme in the UK at approximately €27 million, with annual operating costs of €6.5 million.

An alternative is a mobile monitoring system as offered by CRFS. In their project for Ofcom, spectrum monitoring equipment, contained in standard car roof boxes, was mounted on a fleet of vehicles to perform a preliminary spectrum utilization survey of the whole of the UK. The study indicated implementation expenditure of about €2.7 million and an annual operational cost of about €2.5 million for a UK-wide system. It may, however, be less expensive than this for a regulator to implement mobile monitoring. For instance, the Dutch Radiocommunications Agency introduced a system in which their officers, using CRFS RFeye receivers, gather data whenever they travel on normal Agency business, significantly reducing the costs of operating such a mobile system.[228]

Whether such a system provides suitable data to detect and understand congestion in, for instance, Wi-Fi bands, is a moot point. For urban environments it may also be necessary to monitor signals with handheld devices on foot or even inside the home (Wagstaff, 2008).

A significant question is the scale of the potential enforcement problem in a licence-exempt environment. Under current policies, licence-exempt devices have no right to interference protection. If those sharing abide by the rules and interference mitigation is designed in to the devices, then there will be no basis and no need for regulators to intervene in local conflicts, and no impact on administrative costs.

However, increasing reliance on licence-exempt bands for broadband internet access appears to introduce a potential risk situation: growing dependence on wireless

[228] http://media.crfs.com/uploads/files/1/crfs-radiocommunications-agency-case-study.pdf

infrastructure with no right to interference protection. However, in the light of this, a discussion has already started in CEPT about distinguishing the regulatory status of RLANs from other short-range devices, given that they have global primary status in parts of the 5 GHz band. This may lead to some interference protection for a licence-exempt *service* (RLANs now are merely an *application*). That might mean new enforcement costs, the scale of which is impossible to estimate with confidence at this stage but might require close monitoring in key bands and localities as it is geographically dependent.

A greater number of sharers and heavier use are factors likely to increase the probability of interference but whether that would lead to a need for more enforcement action on the part of regulators depends on where responsibility for interference abatement rests. We think it should progressively shift from regulators to spectrum users, and the many new authorization schemes emerging between licensed and licence exempt provide pathways for that to happen.

The third key component affecting administrative costs is the actual regulatory process itself. In each MS, authorizing licence-exempt devices or introducing a light licensing regime will require a regulatory process to be followed. This will vary considerably by administration and so we make some generic assumption about these processes. First, we assume that the regulatory processes result from the need to implement an EU harmonization decision and so the normal consultation process that would follow a national policy proposal would not be required. However, there would still be implementation costs associated with a consultation, administration and regulation.

### 4.12.2 Estimating the administrative burden of shared spectrum access

Given the array of factors that affect the scale of and responsibility for administrative costs arising from shared spectrum access, we have had to make several assumptions so that we can attempt to quantify the impact. The analysis below estimates the administrative burden for Scenarios 2 and 3 described earlier in this chapter; note that for Scenario 1 there would be no administrative burden by definition. Contrasting scenarios 2 and 3 captures the differences in administrative burden between a more moderate scheme with shared spectrum on a light licensed basis, and a more ambitious scheme with sharing in more bands including licence exempt, in addition to light licensing.

Note that compared with traditional authorization, light licensing or licence exemption implies simpler procedures, fewer spectrum licences awarded through auctions, and a reduction in ongoing licence management. This would mean some savings in administrative costs but also a loss in revenue. Light licensing, however, is still licensing, even though it might mean using the spectrum more efficiently. From our consultations, we estimate that there would be a small saving in implementation costs and ongoing administrative costs in the case of light licensing of 20% compared with traditional authorization procedures.

It is in licence exemption, though, that the potential for savings in administrative costs is greatest. Spectrum licensing, awards, registration and other tasks would drastically reduce administration costs. From a technical perspective, there is now a process of "self-certification" operating in Europe for licence-exempt devices, whereby manufacturers declare that they have implemented the radio interface standard published by ETSI. However, in what would appear to be a legacy from a type-approval procedure, some MS still retain a traditional legislative process to exempt individual devices from their national radio legislation. An alternative is for the regulator itself to exercise control through a licence-exempt regulation, which simply registers devices and is updated annually. The approach should be to make bands for unlicensed use rather than to focus on licence exemption for devices. We conservatively estimate that such a streamlined approach

would represent a saving of 40% in implementation costs over traditional authorization. As for ongoing administrative costs in a licence-exempt regime, here enforcement and administration effectively falls to zero.

Note, however, that administrative burden is calculated on the basis of *additional* costs arising in Scenarios 2 and 3 compared with business as usual, rather than the difference in cost between implementing the changes through a light licensed or licence-exempt regime versus traditional authorization. Thus, for the two options, based on Scenarios 2 and 3, the net costs of implementation and the ongoing administrative burden can be estimated through the following main cost items:

1. Spectrum monitoring and database
2. The regulatory process
3. Enforcement and ongoing administration

In compiling these estimates, we have modelled the costs for a typical large regulator. We have then used a scaling factor of 10 to reach a figure for the EU-27 as a whole.

For spectrum monitoring and a spectrum database, in essence we see this as a cost common to both options. Implementing a mobile spectrum monitoring system is estimated to cost a large regulator €2.7 million with annual operating costs of about €2.5. Thus the costs for the EU-27 are estimated to be:

Implementation costs: €27 million

Annual operating costs: €25 million

In terms of building and maintaining a spectrum database, we assume that on average each NRA would require one full-time equivalent person for this purpose, at €100,000 per year. In addition there would be some computing hardware and software, and database training, which we estimate at about €30,000 per NRA. Thus the implementation cost for the EU-27 would be approximately €3.5 million with annual operating costs of about €2.7 million.

The costs of spectrum monitoring and maintaining a spectrum database might be reduced by NRAs forming regional consortia. A pan-European spectrum database might also be an effective solution, although whether this would be practical, acceptable and cost effective is not clear.

### Option 1: (based on Scenario 2)

In option 1, we assume increased shared spectrum access of 200 MHz authorized in 13 new bands, through some form of light licensing. Implementation costs and administrative burden for Option 1 is estimated in Table 4.22.

Table 4.22. Option 1: implementation costs and administrative burden

| | Implementation costs (€ m) | Administrative burden (€ m) |
|---|---|---|
| Spectrum monitoring and database | 30.5 | 27.7 |
| Regulatory process, IT costs | 21 | 0.1 |
| Enforcement and administration | | 8 |
| **Total** | **51.5** | **35.8** |

The regulatory process costs are calculated as follows. Introducing a new light licensing regime in 13 new bands would require, say, a team of 20 full time people (FTE) for a large regulator (ie comprising 10 policy, 4 engineering, 4 legal and 2 IT), ie 20 x 10 = 200 FTE for the whole of the EU. A cost of €100,000 per FTE is assumed, ie a total EU cost of €20

million. In addition we have assumed IT implementation costs of €100,000 for a large regulator.

The ongoing staff requirement is estimated at 8 FTE for a large regulator (4 enforcement and 4 administration), a total EU cost of 8 x 10 x 100,000 = €8 million. Ongoing IT support costs are calculated at 10% of IT implementation costs.

### Option 2: (based on Scenario 3)

In the second option, in addition to the light licensed bands in Option 1, there are a further 5 lightly licensed bands totalling 300 MHz and a further 2 licence-exempt bands of 50 MHz each. Implementation costs and administrative burden for Option 1 are estimated in Table 4.23.

Table 4.23. Option 2: total implementation costs and administrative burden

| | Implementation costs (€ m) | Administrative burden (€ m) |
|---|---|---|
| Spectrum monitoring and database | 30.5 | 27.7 |
| Regulatory process, IT costs - light licensing | 44.2 | 0.1 |
| Regulatory process, IT costs - Licence exempt | 10 | 0 |
| Enforcement and administration | | 18 |
| **Total** | **84.7** | **45.8** |

Here the cost of spectrum monitoring and maintaining a spectrum database is calculated on the same as in Option 1, Scenario 2. For the regulatory process, in addition to the costs for Option 1, introducing a light licensing regime in 5 further bands would require an extra 3 FTE for a large regulator (ie comprising 13 policy, 5 engineering, 3 legal and 2 IT), ie 23 x 10 = 230 FTE = €23 million for the whole of the EU. In addition we have assumed IT implementation costs of €120,000 for a large regulator.

The ongoing staff requirement in connection with the light-licensed bands is estimated at 10 FTE for a large regulator (6 enforcement and 4 administration), a total EU cost of 10 x 10 x 100,000 = €10 million. Ongoing IT support costs are calculated at 10% of IT implementation costs.

Regarding the licence-exempt bands in the case of option 2, a regulator would require a small team to manage the initial consultation, regulation and administration process. We estimate this would require about 10 FTE for a large regulator (4 policy, 2 engineering, and 2 legal and 2 administration). At an average of €100,000 per head, this would amount to 10 x 10 x 100,000 = €10 million if scaled up across the EU. Thus the net implementation cost for licence-exempt bands in option 2 would be approximately €6.5 million. In terms of enforcement and ongoing administration, we have assumed this would be negligible for the licence-exempt bands.

Therefore, our estimate for the annual administrative burden to NRAs for increased spectrum sharing is similar for both options, ranging from about €35.8 to €45.8 million. The implementation costs for increased shared spectrum access ranges from €51.5 to €84.7 million.

# CHAPTER 5. Conclusions and recommendations

This chapter summarizes the key findings of the study followed by a series of recommendations. A possible roadmap is outlined for Europe to move forward towards increased shared spectrum access.

## 5.1. Maximizing the return on Europe's radio resources

### 5.1.1 Better utilization through shared spectrum access

Exploiting radio spectrum resources efficiently is a fundamental enabler for Europe's economic growth and a key element in achieving the Digital Agenda targets. With the explosive growth in data traffic owing to the rapid take up of smart phones and tablets, the need to relieve pressure on parts of the spectrum is becoming critical. Mobile data traffic is now doubling every six months and Cisco (2011) estimate that, by 2014, mobile data traffic will have increased 37 times over the previous five years. The growth rate of Wi-Fi traffic is even greater. The next generation of cellular mobile and the shift to cloud computing will place further demands on the spectrum.

At the same time, monitoring of the radio spectrum shows that while a few bands are crowded, the vast majority of the spectrum is underused. Spectrum scans made in the centre of Paris, for instance, show average utilization of the 400 MHz to 3 GHz band is only 7.7%. This combination of low utilization in some bands and congestion in others arises in large part because spectrum allocations do not adapt quickly to changes in demand. As a result they reflect past practice rather than future needs. Addressing this misallocation so that the potential of the radio spectrum can be maximized will require a radical rethink of spectrum policies, allocations and management practices. The key to unlocking that potential is to allow, where possible, greater flexibility and shared spectrum access rather than exclusive use. That implies a progressive shift in responsibility for frequency and interference management from regulators to users.

It is necessary to distinguish between shared *allocations* and shared *assignments* or authorizations, because in terms of allocations, the vast majority of the radio spectrum is actually shared. Only 11.2% of frequencies below 3GHz are allocated for exclusive use by a single service. Those exclusive allocations, of course, tend to be in the most attractive parts of the spectrum – between 300 MHz and 3 GHz, where propagation characteristics are most favourable. Future methods of allocating spectrum need to ensure that licence-based regulatory approaches do not result in artificially generated scarcity. Europe's economic development could be jeopardized if frequencies for new applications ranging from e-health to payment systems are unavailable.

Europe is trying to solve the problem of band allocations lagging behind shifts in demand for wireless services by gradually replacing rigid, static specifications of band use with flexible, generic, service-neutral allocations. However, any gains from the allocation level will be limited unless methods are also agreed for increasing flexibility and non-exclusivity

in the use of frequencies. Thus, in order to foster shared spectrum access, new ways to share *assignments* between two or more users need to be explored. Solutions to this have been known since the earliest days of radio: channel sharing, in the form of block assignments, and "spectrum commons" in which there are no assigned channels.

### 5.1.2 Costs and technical challenges of sharing

The costs of sharing in the case of light licensing or LSA comprise those associated with the primary or sharing operator and those associated with the secondary sharer. For a primary operator there will be the costs of a licence but this is likely to be much less than the cost of an exclusive licence at auction. The other main cost items are associated with the network equipment and end-user devices. The devices may have some form of cognitive radio to limit interference and indicate channel availability. Unless the indicator is a simple beacon, the costs of the cognitive infrastructure could be significant – of the order of many hundreds of millions of Euros – though relatively minor in comparison to the overall economic benefit to the EU economy.

### 5.1.3 The impact of 4G

However, there is a further complication. While cellular architecture is recognized as a highly efficient way to provide ubiquitous access to mobile communication services, the cellular industry is seeking an enormous increase in its spectrum allocation (1 to 2 GHz) for the roll out of its next generation 4G networks, which the ITU calls IMT-Advanced. IMT-Advanced has evolved into one of the most ambitious and potentially transformative telecommunications projects ever conceived. It is the largest source of pressure on currently allocated spectrum, with effects on other bands targeted for service displacements and refarming.

In 2006, when the ITU calculated spectrum requirements for IMT-Advanced, no consideration was given to the cost of build out or affordability to subscribers. The idea was to look at the operators' need for bandwidth and the subscribers' desire for data speed and volume as if all resources were free. That may be useful as a way to imagine an ideal network or to identify ultimate goals, but leaving economics out is unrealistic. So we should not be surprised that the requirements based on those assumptions have not proved to be accurate, either.

Most European countries currently have 3 or 4 independent mobile networks. Most or all of them will want to upgrade to IMT-Advanced. But when the ITU plugged its market projections for the years 2010-2020 into software for calculating spectrum requirements, they found that three nationwide mobile networks would need 1560-1980 MHz. Since the recommended frequency range for mobility and reasonable coverage is between 400 MHz and 5 GHz, (ie some 4600 MHz) that amounts to 34-43% of the total range. But it is hard to see how that much spectrum can be made available to IMT-Advanced without severe impact on large numbers of specialized networks and without substantial refarming costs.

Meanwhile it has been realized that the market projections on which the ITU's 2006 spectrum estimates were based are too conservative. Demand is growing far faster than expected. Early in 2012 we should have new estimates from the ITU about spectrum requirements for IMT-Advanced and they are likely to be even larger than the estimates of 5 years ago.

So discussion has already shifted to one-network solutions which might "only" require 1280-1720 MHz per country based on the 2006 estimates. However, the European experience has been that competition in telecommunication network services is essential to progress, efficiency and responsiveness to subscriber preferences. How can competition be preserved in a one-network infrastructure? That is a key question and we hope our

study will draw attention to the need to discuss business structures for IMT-Advanced. If the single network solution translates into a single enterprise, it will certainly have significant market power. If it is an organized group, it will have the features of a cartel. In any form, the market consolidation represented by IMT-Advanced poses great challenges for European regulators.

Another issue which must be of concern to regulators is the fact that the bandwidth needed to support data offloads to "hotspots" was not part of the ITU's calculation of spectrum requirements for IMT-Advanced. However, it is likely that offloading to "hotspots" will be even more essential in 5 years' time than it is today. A 2006 ITU report mentioned that: "One Administration has made some estimates of nomadic spectrum and has shown that this could be more than 50% of the total spectrum estimate." Since their "total spectrum estimate" at the time was 1280-1720 MHz for a single-network configuration, the bandwidth needed to support data offloads from cellular to radio local area networks (RLANs) in the 2015-2020 timeframe could be more than 640-860 MHz. Unfortunately, there is currently only 538.5 MHz of spectrum for RLANs below 6 GHz.

### 5.1.4 Congestion in the licence-exempt bands

We surveyed the 27 EU regulators to get their views on congestion in licence-exempt spectrum: is the problem imminent and how can it be detected. We found that with one exception, none had measured occupancy of any of the five bands used by licence-exempt RLANs for wideband data transmission. Only Ofcom, the UK regulator, has tested a method for measuring the deployment density of Wi-Fi nodes and started work on the next step, which is to translate measurable quantities, like packet loss rates, into user perceptions of degraded performance.

A survey in the UK commissioned by Ofcom in 2008/09 measured a peak Wi-Fi node density of 2247 per km$^2$ and an average Wi-Fi node density of about 1200 per km$^2$ in central London. Although it was only in London that wireless congestion was found to be a significant problem then, recent forecasts of the global growth in Wi-Fi suggest that high-density areas will become much more widespread in future.

The Benelux countries now have Wi-Fi node densities comparable to London but covering a much larger area. Looking to the future, the Wireless Broadband Alliance expects the number of private Wi-Fi internet access nodes in homes and offices to increase globally from 345 million today to 646 million by 2015. During the same period the number of public Wi-Fi hotspots is forecast to grow from 1.3 million to 5.8 million.

Although a great deal of publicity has been given to the need for more spectrum for cellular data traffic, Cisco's Visual Networking Index reveals that Europe's Wi-Fi networks are now carrying 22-25 times as much internet data as all the cellular networks in Europe combined and Wi-Fi data traffic is growing 4-6 times faster than cellular data traffic. Our growing reliance on Wi-Fi networks cannot be ignored just because they are licence exempt.

Despite the lack of systematic measurements, there is anecdotal evidence of growing saturation of the Wi-Fi bands according to our survey of EU regulators: 11 out of 26 of them said they had reports of urban congestion problems in the 2.4 GHz band but their responses to this information vary. Indeed, there is remarkably little agreement among experts on how many Wi-Fi nodes can co-exist in one square kilometre before the degradation of performance becomes unacceptable to users. Unfortunately, the "politeness" built in to Wi-Fi protocols obscures the early warning signs of band saturation: Wi-Fi risks becoming a victim of its own politeness.

In view of the technical challenge of detecting devices with such short ranges, and the length of time it can take to identify a new band for licence-exempt use, there is a clear need for regionally consistent and more accurate early indicators of congestion in licence-exempt spectrum. CEPT has recognized the need for more active monitoring of conditions in licence-exempt bands but so far has not initiated systematic studies. A mandate from the Commission could stimulate activity in this area.

### 5.1.5 Light licensing requires specific consideration

Authorised Shared Access (ASA) is an approach to spectrum sharing proposed by Qualcomm and Nokia in January 2011 in their joint response to an RSPG consultation. If adopted by regulators, ASA would enable licensed users of radio spectrum to loan their channels temporarily on the basis of negotiated agreements with a certain number of borrowers. Cognitive radio techniques – beacons, geolocation databases, sensing, etc. – would be used to establish when the channels are available. Agreements between the borrower and lender would be registered with the regulator and would probably involve some compensation to the lender in exchange for some guaranteed minimum availability of channel use-time in specific areas. ASA differs from traditional band sharing in that it is not a static arrangement set by the regulator. It adapts to short-term changes in availability and demand for channels, which should lead to a higher degree of spectrum utilization. ASA also differs from the emerging "white space" model in that the channel borrowers would be limited in number, licensed and subject to the terms of a negotiated agreement. Under WSD rules, there are no negotiations with incumbents, the number of opportunistic users is unlimited, their identities unknown. That increases apprehension among incumbents that if interference is caused, it might not be possible to identify the source and find a remedy.

ASA's proponents suggested that the scheme might be applied to the 2300-2400 and 3400-3800 MHz bands, which are designated for the use of cellular mobile networks although cellular is not yet deployed there. The hope seemed to be that ASA would enable faster cellular build outs if agreements are reached with the existing band users. But ASA is not tied to the cellular industry or those specific bands. The Radio Spectrum Policy Group sees it as potentially useful in many situations, so they have elaborated the concept into Licensed Shared Access (LSA).

LSA differs from ASA mainly in perspective and emphasis. The perspective is regional and the emphasis is on the role of regulators in creating a harmonized framework for the agreements between licensees. A regional framework is needed because both ASA and LSA are based on temporary sublease arrangements and ECC Report 169 found that at least eleven CEPT members do not currently permit the subleasing of radio channels. LSA would also require regulatory approval of each sharing agreement, because agreements would be considered amendments to the licence conditions. The regulators' role may thus be more crucial in LSA than in ASA.

ASA or LSA could also be used to encourage new sharing arrangements between governmental primaries and commercial secondaries, to get more value out of public sector spectrum. In fact, the UK Ministry of Defence recently advertised the availability of frequencies at 3500-3580 MHz and invited the public to apply for paid access rights to 5 additional bands under an arrangement similar to ASA. In general, adaptive sharing is an improvement over static arrangements so we welcome this development.

The Authorisation Directive (2002) established general authorization as the EU's preferred approach to the regulation of spectrum access, with "individual rights of use" (licensing) used only when necessary. Since the Directive has been in force for 10 years one might have expected more progress by now in reducing the use of licensing. But that is not the

case. We consider why in our study, but suffice it to say we see the many forms of light licensing as pathways toward liberalization and licence exemption. With the new emphasis on shared spectrum access motivating our research, we hope to see more EC leadership in coming years, in the form of coordinated transitions from individual to general authorization, from exclusive to shared access. The maritime mobile service would be a good place to start as pleasure boats, fishing vessels and the like are obvious candidates for light licensing, even for de-licensing – and some Member States have already moved in that direction. Recognizing that propagation distances above 100 GHz are limited and directional antennae are easily constructed and effective at these frequencies, the overall risk of interference in the higher GHz bands is very small. As a result, several administrations have looked into the option of making licence exemption or light licensing the default authorization schemes above a certain frequency. We support these proposals and believe they are what the Authorization Directive requires, while noting that applications which use these frequency bands will be short range.

### 5.1.6 Overcoming barriers through incentives and penalties

One of the main barriers to greater sharing of radio channels is that many current licensees have enjoyed exclusive spectrum usage rights for a long time. They have adapted to slow equipment replacement cycles and stable business processes and they expect these to continue indefinitely. Incentives and reminders of their limited tenancy may be needed to change these expectations. One obvious incentive is to compensate incumbents for letting new users share "their" spectrum. If the new users are themselves willing to pay, the net cost to regulators could be minimal.

The UK's audit of spectrum holdings (the Cave review) made wide-ranging recommendations on public sector spectrum use, including Administrative Incentive Pricing (AIP), so users appreciate that allotted spectrum has value, as well as the encouragement of band sharing with non-governmental radio systems. These recommendations are beginning to yield results replicable in other European countries.

In broadcasting, new market forces conducive to sharing are emerging. For broadcasters, wireless broadband will become increasingly attractive for delivering audiovisual content on a schedule set by the viewer. The broadcasters' willingness to cede spectrum to mobile networks and broadband – or to form partnerships with firms active in those sectors – may grow if current trends toward inter-industry collaboration and media hybridization continue.

In the cellular industry, network operators are under pressure to offset declining voice revenues with new services and cost-saving strategies. There are compelling economic arguments for cellular networks to make more use of licence-exempt spectrum – not just for offloading or to gain more control over their subscribers' use of Wi-Fi, but to reduce the cost of network expansion. The first two cellular networks established in licence-exempt spectrum are now operating in the US and eight more are expected to launch in 2012. Field tests of LTE in TV white spaces have begun, and it has been suggested that femtocells might also use TV white spaces to avoid interfering with macrocells. We anticipate that the technical means for ensuring adequate quality of service in licence-exempt spectrum will continue improving so that MNOs may have no reason not to follow their customers into shared access spectrum if regionally harmonized and affordable licensed spectrum is not available in sufficient quantity.

On the other hand, incentives and market forces may not be enough to persuade every licensee to accept more channel sharing. Regulators might also need to consider modifying the conditions of individual authorizations so that licensees can lose their exclusivity if a review finds their use of spectrum falls below a level justifying their current access rights.

That would be a softened implementation of the "use it or lose it" policy articulated by Vice President Neelie Kroes in her speech to the 2010 Spectrum Summit: "If the potential of a spectrum allocation is not being exploited to its maximum, if the application is not the most efficient way of delivering social, cultural or economic benefits, then it should go to another application or service instead."

### 5.1.7 Benefits of shared spectrum access for wireless broadband

Data from Cisco, IDATE and other sources show that Wi-Fi is the most popular access medium for the internet in Europe. In other words, shared spectrum access already accounts for most of the socioeconomic benefits of wireless broadband. Moreover, the proportion of broadband data supported by shared spectrum access will expand over the next five years. The study team believes that increasing allocations of shared access spectrum for wireless broadband could provide a significant economic stimulus to the EU economy and bring additional social benefits to Europe's citizens.

A quantitative assessment of the economic impact of increased shared spectrum access for wireless broadband was attempted as part of the study, and this is described in detail in Chapter 4. The basic assumption made was that more shared access is equivalent to extra spectrum and it is through exploiting this "new" spectrum that the major economic benefits of shared spectrum access accrue. Scenario simulations yielded estimates of the net economic benefit to the EU of shared spectrum access for wireless broadband. These show significant returns, taking into account the range of uncertainties of such modelling. Total net increases in GDP over nine years to 2020 were estimated at between €200 billion to over €700 billion in the two scenarios, which posited allocation increases of 200 and 400 MHz, respectively. However, taking into account the range of uncertainties of this modelling, the margin of error in our calculations is such (+/- 50%) that these quantitative figures should be considered as indicating the order of magnitude of the impact of shared spectrum access rather than an accurate prediction.

To explore the possibilities, three different scenarios were considered.

***Scenario 1: "No change for the better – a baseline scenario".*** The scenario continues today's spectrum conditions forward into the future. There are no changes in regulation to increase sharing so the scenario just assumes continuing "business as usual" with emphasis on using what is already permitted. The implications of this are saturation of spectrum in around five years due to demand for data traffic at broadband speeds and the entry of LTE. Authorised Shared Access (ASA) type sharing, in those Member States, where it is permitted, becomes more necessary, especially as LTE enters. The range of frequency bands used for sharing in Scenario 1 shown below:

| Type of sharing | Band position | Spectrum width, MHz | Value |
|---|---|---|---|
| Existing Wi-Fi bands | 2.4 and 5 Ghz existing allocations of licence-exempt swathes | Existing allocations (total 538.5 MHz) – no new spectrum | Med/High |
| MNO sharing with LSA/ASA (where already used) | GSM and UMTS bands | GSM & UMTS standards for channels | Low |
| Unlicensed bands allocated today | Existing ISM bands | As for existing allocations only | Low |
| **New** shared bands, total MHz | | 0 MHz | |

Spectrum saturation implies various negative effects – for instance, auction prices for spectrum rise and this is passed on to the customers in higher tariffs. There is saturation in

urban and suburban areas for use of Wi-Fi. Data roaming across the EU does not become a low cost service, while caps on volumes of data are universal, so that even with LTE, wireless broadband has restricted coverage and data rates. Existing mobile services are not able to satisfy the demand for mobile data traffic in exabytes (the level of pent-up demand by 2015), and Wi-Fi offers only limited relief. Elevated data charges are justified by the need to throttle the high volumes of data traffic. The commonest use of wireless for internet access is from picocells in the home or office, supplied via an xDSL copper or direct fibre connection for backhaul. Thus, in this scenario, there is some uncertainty as to whether wireless broadband could provide comprehensive coverage of the EU to meet the DAE target of 30 Mbps for every household within the 2020 timeframe.

***Scenario 2: "Something stirring – modest sharing".*** In this scenario there is a modest increase in unlicensed spectrum for fixed/nomadic/wireless broadband: overall, some 200 MHz is made available via expanded sharing, through white spaces with cognitive radio, also SRD expansion and light licensing, as shown in the table. This is important for the EU as for the first time universal coverage becomes possible for fairly high speed data rates (on the order of several Mbps). The key conclusion is that sharing offers a significant potential economic stimulus for the EU economy.

The costs are largely due to the build and operation of a lightweight infrastructure based on Wi-Fi type technologies and white space devices (WSDs). The order of network costs are estimated to be in the high hundreds of millions of Euros, up to several billions if the cost of additional software and hardware incorporated in the mass market handset device is included. To this should be added the costs of commercial agreements charged per year. Agreements include light licensing and Administered Incentive Pricing (AIP) accords with the incumbents, especially the public services and the broadcasters for interleaved and direct spectrum sharing, based on transmission constraints (temporal, power and frequency, etc) for the secondary users. These vary in cost, depending on bandwidth and population coverage, but represent in total a billion Euros per year (based on an AIP cost of €300,000 per million population, for sharing of 10 MHz, a price which may well increase with time). That gives an estimated accumulated cost of agreements over nine years for the whole of the EU of up to fifteen billion Euros.

One foreseeable result of Scenario 2 is the development of more large-scale user-owned networks, as in Catalonia, Spain, where Guifi.net's 24,300 km of wireless links serve 15,000 households at very low cost. This model yields major benefits, not just for social cohesion and affordable residential communications, but for telemedicine care functions such as in-home monitoring. The key bands envisaged in Scenario 2 are summarized below:

| Type of sharing | Band position | Spectrum width, MHz | Value |
|---|---|---|---|
| Existing Wi-Fi bands 2.4 and 5 GHz licence exempt, ASA sharing, Unlicensed bands allocated today for ISM | | | |
| Broadcast sharing using LSA/ASA | 55-68 MHz<br>174-230 MHz broadcasting | 13 MHz<br>56 MHz | High<br>High<br>High |
| MNO sharing with LSA/ASA | 860-870 MHz<br>2100-2120 for SRD only | 10 MHz<br>20 MHz | High/medium (dependent on conditions)<br>High/medium (dependent on conditions) |
| Military and other public services shared bands – all releases under AIP, for 4 year agreements | 870-872 MHz<br>915-917 MHz<br>1427-1452 MHz<br>2025-2070 MHz<br>4800-4840 MHz<br>10-10.025 GHz | 2 MHz<br>2 MHz<br>25 MHz<br>45 MHz<br>40 MHz<br>25 MHz | Low except for RFID or white space 'keyholes'<br>High<br>Medium<br>Low/Medium<br>Low |
| **New** shared bands, total MHz | | **200 MHz** | Averaged: medium |

The light sharing network is based on a layered architecture – firstly a radio access network based on technologies such as cognitive radio and databases of available slots as well as Wi-Fi in the licence-exempt bands at 2.4 and 5 GHz. The second layer provides backhaul from the access points into internet spines at low cost. This could be via microwave, directional Wi-Fi, or LEO micro-satellite, HALES or MEO satellites, as appropriate for the data volumes and acceptable latencies.

***Scenario 3: "Sharing takes off – and the economy".*** Here the net sharing bandwidth doubles to 400 MHz including the establishment of 100 MHz in licence-exempt band in two blocks, one of 50MHz in the sub-1 GHz block, and one in the 1400Mhz band, both usable for wireless broadband directly, and for longer range Wi-Fi or WiMAX to accommodate offloaded data from cellular mobile networks. The dispositions of the sharing bands are summarized below:

| Type of sharing | Band position | Spectrum width, MHz | Value |
|---|---|---|---|
| Existing Wi-Fi bands 2.4 and 5 GHz licence exempt, ASA sharing, bands allocated today for ISM | | | |
| As for Scenario 2 – But with variations in width of broadcasting, military and other public services and MNO bands shared under AIP | | | |
| Unlicensed bands allocated today | Existing ISM bands | Existing allocations – no new spectrum | Low |
| Broadcast sharing | | Total 111 MHz | Very high/high |
| MNO sharing | | Total 80 MHz | High/medium |
| Licence-exempt new bands in Digital Dividend | 535–585 MHz | 50 MHz | Very High |
| Licence-exempt new bands in upper UHF | 1442–1492 MHz | 50 MHz | High |
| Military and other public services | | Total 109 MHz | Low except for RFID or white space |
| **New** shared bands, total MHz | | **400 MHz** | Averaged: medium/high |

From the analysis, the third scenario is the most generous and open scenario for shared access, so that the *net* increase in value to the European economy is higher than in the second scenario. Refarming to create new licence-exempt bands presents a major cost element. However, refarming costs vary greatly depending on how the sharing is implemented. The most expensive condition is when the incumbent is forced to replace equipment and possibly business processes, imposing a need for new capital investment while established revenue streams are interrupted. The least expensive is where programmable channels can be reselected by both emitters and receivers, with no need to replace equipment. Frequency agile equipment will be increasingly important as flexibility and dynamism become the new norms in spectrum management.

The radio infrastructures envisaged for sharing would principally be either those with transmitters which can change their frequency and power characteristics in the presence of other signals or those that are permanently set up to avoid interference by means of geographic, temporal or power limitations. The minimum costs of such an infrastructure were estimated for the scenario conditions to be of the order of a hundred billion Euros but could be less in some circumstances. For instance, there can be re-use of some mobile infrastructure (eg base station site co-location – rental sharing, common facilities for power, cooling and backhaul, etc). In Scenario 3, the aim would be to cover a major portion of the EU with wireless broadband, which could be engineered to support the European Digital Agenda targets of 30 Mbps for the remaining EU households unable to connect to a fixed broadband network (about 5% in total and 17.5% of the rural population).

For the handsets and access points, newer models with software defined radio (SDR) front-ends will be able to follow frequency changes. This can be the case whether the new units are fixed in frequency or adaptive, for dynamic spectrum access. In high volume production, the additional software and hardware could be of the order of twenty to thirty Euros per handset at introduction, expected to fall to a fraction of that in two or three years if production volumes were in the hundreds of millions, but with higher costs for the access points.

### 5.1.8 Impact on cellular of more broadband in shared access spectrum

What would be the impact on existing cellular mobile networks of more shared access spectrum for broadband? Our conclusion is that sharing spectrum will increase competition for data and voice roaming services, to the benefit of the consumer. The study views Wi-Fi and other RLANs as potential substitutes for cellular roaming services and also considers they can provide enough competitive pressure on MNOs to reduce retail prices for roaming. But regulatory vigilance will be needed as MNOs are rapidly expanding their involvement in the development of public "hotspot" networks. MNOs are likely to wish to maintain or enhance roaming's current profitability (retail prices are still significantly higher than the costs of service provision). That could lead to carrier-mandated restrictions on hotspot-based services for cellular customers in order to protect revenues. However, if regulators can prevent anti-competitive responses by MNOs to the expansion of broadband access through public hotspots, benefits to the European economy could be substantial.

Simply mitigating the fear of "bill shock", which prevents about 40% of cellular subscribers from using data roaming services at all, will increase the usage and thus potential productivity of frequent travellers. Generally speaking, lower costs for mobile broadband and voice services will enable more people to participate in and benefit from the information society. This could, according to Scenarios 2 and 3 of our study, impact the majority of EU citizens. Also, examples of socially valuable services supported by wireless broadband include caring support in the home for aged persons, telemedicine,

advancing personal aspirations through augmenting education, including vocational training and job search, as well as maintaining the integrity of dispersed families.

### 5.1.9 Orchestrating future spectrum management for sharing

Our survey of FP7 projects found that current regulations would not seriously impede the introduction of most of their new wireless technologies, some of which seem especially promising for ultra-high speed mobile networking. Many FP7 projects are working on aspects of dynamic spectrum access and cognitive radio, concepts which could have a major impact on the way we regulate and use radio as early as next year, if regulators in the Member States open UHF "white spaces" to opportunistic sharing. A number of FP7 projects recognize a common pattern emerging from their work. It has come into focus as a need to migrate from rigid/static to flexible/dynamic spectrum authorization.

This is our main conclusion as well.

In terms of our task of identifying technical usage conditions which need to be changed to facilitate the use of innovative sharing techniques, regulatory approval of the cognitive use of "white spaces" tops the list. Unfortunately, our survey of national regulatory authorities found that only 7 of the 26 respondents plan to authorize white space devices (WSDs) in the near future, though 3 more are undecided. In addition, the rules designed to protect television broadcasting, wireless microphones and other UHF applications could prove quite burdensome for WSDs: even in the countries authorizing their use, WSDs could fail in the marketplace if regulatory requirements make the equipment costs too high and the deployment options too limited. (Because of regional harmonization, maximally strict requirements for the protection of incumbent services will apply even in countries with few over-the-air DTT viewers.) Failure of WSDs in the marketplace could affect the commercial development of cognitive radio in Europe even more adversely than if they had not been authorized. On the other hand, there are other developmental pathways for cognitive radio: geolocation database lookups by RLANs in the 5 GHz band, and time-sensitive techniques to support ASA/LSA sharers, for example.

At a more general level, the main change in technical usage conditions which we have identified is the need for CEPT compatibility and sharing studies to assume a more flexible framework for interference management when evaluating whether two or more systems can co-exist. That may result in more authorizations contingent on agreements among users to cooperate in identifying and resolving interference issues. The cost/benefit impact of such a change is difficult to quantify as there is no standard objective definition of "acceptable" interference and all band sharing arrangements are to some extent unique. But a 2007 study of interference regulation for the Commission found that "further modification of methods and/or modified approaches could lead to significant spectrum gains. Based on our investigations a loss of efficiency of between 30% to 50% of the theoretical possible figure is currently being experienced" as a result of rigid and simplistic band sharing arrangements (Eurostrategy/LS Telecom, 2007).

As to the question of how much additional spectrum is needed for shared spectrum access, we defer to the Authorisation Directive, which makes general authorization the preferred option for radio spectrum access. This fundamental policy principle is sufficient justification for maximizing additional allocations of spectrum for *non-exclusive* use. It is licensed exclusivity which must be justified by need, not shared access. Asking how much licence-exempt spectrum is "enough" is not appropriate.

This is underpinned by the fact that the licence-exempt spectrum in which broadband access to the internet is currently authorized is already supporting many times more users and traffic than experts had thought possible. Moreover, the difference between normal

and congested conditions is difficult to discern in Wi-Fi because of the protocol's innate politeness.

Band saturation owing to data traffic is still an obvious risk, however, with the Cisco Visual Networking Index forecasting an almost five-fold increase in data traffic flowing through Wi-Fi nets between 2010 and 2015. Wi-Fi is now proliferating into almost every product family, from refrigerators to picture frames to automobiles. There is a rapid growth of video streaming, in the 2.4, 5 and 60 GHz bands, expected to drive an "exaflood" of data offloads from cellular; and the possibility that even cellular networks might start exploiting licence-exempt spectrum.

The study team believes that an additional 400 MHz of shared access spectrum, including 100 MHz in licence-exempt bands, offers substantial benefits to the European economy, including the alleviation of congestion in the already crowded exempt bands.

There is also a need for regionally harmonized procedures for the early detection of congestion in licence-exempt bands. For that reason we recommend convening a regional conference to discuss and develop consensus on the best practices for detecting and measuring congestion in the bands used by SRDs and WAS/RLANs. The results of this conference could be important inputs to a CEPT report on this topic.

The discussion which has started within CEPT (in the Maintenance Group for SRDs) on the need for different degrees of interference protection for various types of licence-exempt equipment is both timely and important. It is not necessary to offer complete protection rights as licensed primary services enjoy. But it is both possible and beneficial to consider privileging certain classes of equipment – for example, medical devices, where life itself could be at risk from excessive radio interference, and wideband data transmission systems (as that phrase is currently defined in ERC Recommendation 70-03), which a majority of EU citizens use for Internet access.

### 5.1.10 Impact on administrative costs for regulators

Increasing the use of shared access spectrum may affect the costs of equipment and/or regulation. A number of factors influence the size of the impact and who bears what share of the cost, including:

- How much spectrum is shared and in which bands
- The interference risk, which depends on the number and distribution of sharers, their quality of service requirements, the signal power and modulation, channel use patterns, etc.
- The authorization framework(s): licensed, light-licensed or licence exempt
- The basis for sharing, eg politeness protocols, spectrum/location database lookup, negotiated agreements, etc.

So, for instance, if sharing were performed using politeness protocols, this would require a small amount of additional hardware and software. If this was applied on a licence-exempt basis, the costs would fall on the unlicensed sharer. Rule changes and periodic allocation reviews would be the only sources of administrative cost and these are not likely to be significant.

If, however, sharing is based on a spectrum/location database infrastructure operated by the regulator, there would be higher administrative costs. The basis for a spectrum use database is monitoring, and the cost of that monitoring depends on how often band scans are needed, the extent to which they can be automated, and on the frequency range of interest (higher frequencies require monitoring from more locations and that may require

mobile monitoring equipment to limit the number of sites needed). We foresee increased requirements for monitoring as regulators rely less on individual licensing. But the purpose of monitoring should also shift gradually from enforcement to support for re-allocation decisions and verifying efficient use.

A key question is the potential impact on administrative costs of changing the amount of flexible use and licence-exempt spectrum. Given the array of factors affecting these costs, we had to make some assumptions in order to quantify the impact in our three scenarios. For Scenario 1 there is no additional administrative burden, by definition. But comparing the other two scenarios reveals the differences in administrative burden between a moderate scheme based on light licensing and a more ambitious scheme based on a mix of exempt and lightly licensed bands.

In theory, an increase in light licensing or licence exemption could imply less traditional authorization, and fewer spectrum licences awarded through auctions. This would mean some savings in administrative costs but also a loss in revenue. Light licensing is still licensing, even though it might mean using the spectrum more efficiently. Thus we have estimated the administrative savings from light licensing at 20% of traditional authorization costs. It is in licence exemption, though, that the potential for savings in administrative costs is greatest. Spectrum licensing, awards, registration and other tasks would drastically reduce administration costs. We conservatively estimate that such a streamlined approach would represent a saving of 40% in implementation costs over traditional authorization. As for ongoing administrative costs in a licence-exempt regime, here enforcement and administration effectively falls to zero.

Note, however, that administrative burden is calculated on the basis of *additional* costs arising in Scenarios 2 and 3 compared with business as usual, rather than the difference in cost between implementing the changes through a light licensed or licence-exempt regime v traditional authorization. The net costs of implementation and the ongoing administrative burden can be estimated through the following main cost items:

1. Spectrum monitoring and database
2. The regulatory process
3. Enforcement and administration

Of these elements, a comprehensive spectrum monitoring system across the EU is likely to be the major administrative burden. Our estimate for the administrative burden to NRAs for increased spectrum sharing is quite similar for both Scenario 2 and 3, although of course Scenario 3 represents a doubling of the increase in shared spectrum access compared with Scenario 2: the annual administrative burden to NRAs is about €35.8 million for Scenario 2 and about €45.8 million for Scenario 3. The implementation costs for increased shared spectrum access ranges from €51.5 to €84.7 million.

In escaping from older systems of administration, industry structures and technologies, Europe's legislators and regulators will need new principles for apportioning spectrum. The case for a more flexible approach to spectrum management is compelling, but the change required is significant and the difficulties facing regulators and users should not be underestimated. European level cooperation will be required if regulators are to embrace the more flexible strategic role that may be necessary in the future.

## 5.2. A summary of findings and recommendations

The table below briefly summarizes the findings of the study by task:[229]

| |
|---|
| Task 1<br>• Examines in 3 scenarios the impact of applying sharing for wireless broadband.<br>• Benefits from driving the EU economy vary by scenario. A significant economic stimulus can be achieved by increased sharing of radio spectrum.<br>• Variations are due to the form of sharing, the bandwidth made available and the costs of sharing including, in one scenario, refarming of some incumbents.<br>• In consequence, even though the alternatives to traditional mobile and direct influences on its pricing may be limited, spectrum sharing's effect on the market may be assumed to have a wider leverage affect, touching the majority of users through the rebalancing of existing tariffs as well as added capacity.<br>• Social benefits are significant as wireless broadband can offer households and individuals internet access in rural, suburban and urban settings varying from several Mbps up to 30 Mbps, depending on the implementation scenario. |
| Task 2<br>• Industry trends and developments most relevant to shared spectrum access are:<br>  • Accelerating growth in wireless data traffic generated by smart phones, tablets, and other portable internet access devices.<br>  • The resulting need to expand cellular mobile networks rapidly, including backhaul, and to accommodate an "exaflood" of offloads into licence-exempt spectrum below 6 GHz.<br>  • The proliferation of SRDs.<br>  • Tentative movement toward a "strategic partnership" between broadcasters and mobile broadband networks.<br>  • Tentative interest among regulators in exploiting "white spaces" as a way to increase spectrum utilization in predominantly licensed bands.<br>• Few FP7 projects see any need to change "shared allocations" in order for their technology to enter the marketplace. But projects developing "white space" devices favour rule changes to enable the deployment of their technology. A general pattern emerging from the FP7 radio projects is the urgent need to replace static/rigid forms of spectrum assignment with dynamic/flexible ones.<br>• "Politeness" rules enable more sharing but can be a source of inefficiency in channel use. Better coordination is needed between standards groups to improve compatibility between different new radio technologies.<br>• On the need for more "shared access spectrum" we consider an additional 300-400 MHz is needed, including 100 MHz in new licence-exempt bands. |
| Task 3<br>• NRA knowledge of use of shared access bands for wireless broadband, congestion and interference is mainly anecdotal. Only one has measured occupancy of any of the five bands used by licence-exempt RLANs.<br>• Nevertheless, 11 NRAs report that congestion at 2.4 GHz is increasingly widespread in dense urban areas in their countries. The rate of traffic growth means problems will increase, although there is no consensus on an acceptable upper limit of Wi-Fi node density.<br>• To relieve congestion, we propose the bands in Scenario 2, as given in the table above, and for Scenario 3 we also propose an additional licence-exempt band in the 500-600 MHz region as well as one at around 1400 MHz, each of 50 MHz. |
| Task 4<br>• The annual administrative burden to NRAs for increased spectrum sharing is about €35.8 million for Scenario 2 and about €45.8 million for Scenario 3.<br>• The implementation cost is about €51.5 million for Scenario 2 and €84.7 million for Scenario 3. |

[229] See Chapter 1.2 for a full description of the study tasks.

Task 5
- The ASA and light licensing bands suggested are given in the frequency tables above.
- ASA's proponents suggest applying that regime in the 2300-2400 MHz and 3400-3800 MHz bands to accelerate the build out of cellular networks. However, others in the cellular industry say sharing with other systems is rarely feasible.
- On the other hand, ASA or LSA may be useful in inducing a public sector primary to share with a commercial secondary.
- Light licensing is such a flexible authorization regime that it could be applied in many bands, first among them being maritime mobile, but also in many bands above 100 GHz.

As well as addressing the specific objectives of the study defined by the tasks above, we have identified a variety of ways in which progress towards shared spectrum access and its use for wireless broadband could be supported. These recommendations are gathered together in the box below:

| Box 5.1. Supporting shared spectrum access: recommendations |
|---|
| To accommodate future wireless broadband requirements, in the light of expected demands for offloading of data traffic from IMT networks, establish two new swathes of licence-exempt spectrum in the UHF region, one below 1 GHz and one above 1 GHz, of the order of 40-50 MHz each and dedicated to Wireless Access Systems including Radio Local Area Networks (WAS/RLAN). |
| Moves towards general authorization with light licensing and de-licensing should be pursued for advancing the sharing of spectrum, in line with the Authorization Directive. Here LSA and ASA are steps on the way to more shared spectrum and should be endorsed as ways of persuading government primary holders of spectrum rights to open shared access to commercial secondary users. |
| The management of variable higher power output limits for Wi-Fi and WAS/RLANs in rural areas should be authorized to reduce the cost of broadband internet access. Databases with location awareness and CR could be used to enable this. |
| Regulators should consider modifying the conditions attached to individual rights of use (licences) in certain services so that channel or geographic exclusivity can be suspended if a regulatory review finds a licensee's utilization of their assigned spectrum is consistently below a level justifying exclusivity. |
| For receivers, higher performance standards for interference rejection and selectivity should be considered. |
| It would be beneficial for ETSI to accept the possibility of active adaptation between two or more different system types developing new technical conditions for band sharing. Active adaptation and cooperation could be made a condition of authorization. |
| Some EU members do not currently allow spectrum subleases, so regional harmonization of the framework enabling the negotiation of sharing arrangements based on subleases is needed |
| Better and faster coordination is needed between standards groups to improve compatibility between new radio technologies. Moreover, regional initiatives are required to coordinate administrations in migrating specific services (eg maritime mobile) from individual to light licensed and general authorizations. Thus to focus co-ordination, it would be helpful to organize a regional conference to review and seek consensus on "best practices in defining and detecting congestion in licence-exempt bands", from technical, standards and regulatory viewpoints, with formation of a ginger group to coordinate the transition to a more flexible spectrum management framework. |

Even though most parts of the radio spectrum are under-utilized, regulators still find it difficult to accommodate new services and alleviate the pressures caused by large and rapid shifts in frequency demand. The combination of low utilization and the inability to accommodate new demand shows that the way spectrum is managed must become more adaptive. That is to say, less rigid and more flexible.

The Commission's recognition of the need to move away from fixed, exclusive and persistent channel assignments is reflected in a growing emphasis on "shared spectrum access". What is needed, in addition, is an understanding of why regulators embraced inflexible and exclusive channel access principles in the first place. It was due to the priority given to interference prevention in the early days of radio, which became an unquestioned assumption and remains a top priority today. But the opportunity cost of this policy is very high. The underutilization of spectrum which we see today is the direct result of a century of commitment to guaranteeing on-demand access to exclusively assigned, interference-free channels.

There is, unfortunately, a conflict of interest between the protection of incumbents and the accommodation of new users. What is needed is an agreed incremental expansion of allocations in which interference-free channels are not guaranteed, where users accept responsibility for dealing with interference on their own, and where equipment suppliers have incentives to develop more polite and robust equipment. In other words, a gradual shift toward more shared access and licence-exempt spectrum.

The economic benefits of this shift are hard to quantify, but the study team believes they could be significant. Wi-Fi seems to be a magnet now for data traffic and innovation. But it is not Wi-Fi which is the magnet, it is the intimation that there could be another way to manage spectrum: a way based on the principle that anything is permitted which is not forbidden, rather than the principle which has ruled radio since the start: that everything is forbidden except what is authorized by the state. If there is to be a transition from one mode of thinking to the other it must be evolutionary. Shared access to spectrum under progressively less restrictive technical conditions, is the way.

## 5.3. Moving forward – the path to increased spectrum sharing

### 5.3.1 Policy options

We can envisage a limited number of policy options to promote greater access to shared spectrum, which largely correspond to our scenarios. These range from doing little or nothing to fully embracing sharing in order to stimulate the EU economy, enabling wireless broadband to be rolled out with EU-wide coverage as quickly as possible:

1. *Do nothing:* But is this really an option? Pressures are mounting for more spectrum access from different parts of the ICT industries, be it the MNOs wanting more licensed bandwidth and unlimited "hotspot" offloads, or the chip manufacturers, the consumer electronic manufacturers/services operators and the internet players wanting more shared access spectrum.
2. *Promote a simple but limited economic agenda:* The strategy would be to encourage economic growth through increasing spectrum access using sharing in a limited fashion, much as in Scenario 2. It thus implies a push for new networks built on sharing spectrum, hopefully leading on to lower cost communications. It corresponds to a light interpretation of the sharing potential, with an ad hoc approach using LSA/ASA/WSD with existing LE bands for Wi-Fi.
3. *Embrace sharing to accelerate the EU economy by promoting universal coverage by wireless broadband:* Here the aim would be to open up spectrum access for everyone –

business, communities and the 'radio-based industries' – to benefit from EU-wide wireless broadband. Realistically this would be a longer-term goal, ie with first fruition by 2020. This implies a progressive restructuring of the mobile services industry and its current business model – perhaps through the consumer device and content segments, a trend which is already in process. It would enable ad hoc, user-defined and perhaps even user-owned/operated networks, without an organizing operator.

In our view, doing nothing is not an option. For the second or third options, the first necessary step is to examine the market and regulatory landscape regarding the use of the spectrum – the demand side, the supply side and the administration (regulators and government). Compared with the past hundred years, in future the balance between these three is changing rapidly, so that spectrum management should be far more sensitive to the demand-side – the end-user and citizen – and not just the traditional incumbent suppliers of services – broadcast, government services and cellular mobile. Furthermore, the supply side itself will evolve as the product manufacturers for consumer electronics and computing, the semi-conductor industry, as well as the web services segment combine to become more strident in their demands for a voice in deciding on the future of spectrum management. These ICT industry players tend to favour open spectrum access. They see the restrictions for reasons of protection from interference as incompatible with both modern digital signal processing techniques and their business models of bundled radio connectivity. This implies a quite different spectrum management environment in future.

### 5.3.2 Overcoming the three key barriers to increasing shared spectrum access

Increasing shared spectrum access first requires sensible and pragmatic regulation, then persuading the incumbent holders of licences to accept non-exclusivity and, finally, harnessing technology. The regulatory targets for sharing require an agreed framework of conditions that avoids disruption and chaos – but also without timidity in the face of exaggerated warnings of interference. Thus:

- Existing licences should be respected
- Formal agreements on refarming of existing licences need to be negotiated
- Devices operating in licence-exempt bands must be encouraged to develop more robust interference management techniques.

Second, the three key incumbent groups will require incentives if they are to be persuaded to share or relinquish spectrum. For example, for broadcasting, the commercial attraction of web distribution of content should be emphasized, highlighting alternative channels for TV to replace DTT (ie CATV, satellite, fixed line broadband, as well as Web TV over wireless broadband). For the MNOs, the benefits of a more flexible approach to spectrum use, including shared access with other types of user, should become increasingly attractive as they consider new market opportunities in multimedia over 4G and Wi-Fi networks. In the public services, the way forward is encouragement through AIP in times of austerity in public finances.

### 5.3.3 Progressing to a shared use of spectrum – a new management regime and economic status

A new approach is needed for spectrum administration to match a new strategy for spectrum usage and its management, with a progressive legal regime. Traditional regimes of spectrum regulation are based on the overarching principle of forbidding everything, then permitting precise exceptions only with explicit permission (licences). In contrast, the

sharing principle for spectrum regulation would move to allowing anything which is not explicitly prohibited, with users gradually assuming more responsibility for frequency and interference management. Therefore a new foundation for spectrum management would have different characteristics for both regulation and the economic and legal status of spectrum:

Table 5.1. The management framework for sharing spectrum

| Attribute | Today | Tomorrow |
|---|---|---|
| **Regulator's role** | Controller and commander | Co-ordinator and facilitator |
| **Decision criteria** | How many users | How much interference |
| **Economic & legal status of spectrum** | Marketable property – restricted economic benefit, from sale to 'owner' | Publicly owned commodity - widespread economic benefit from sharing |

### 5.3.4 A three-phase roll-out for increased spectrum sharing

A transition to a new spectrum management regime will require a phased approach:

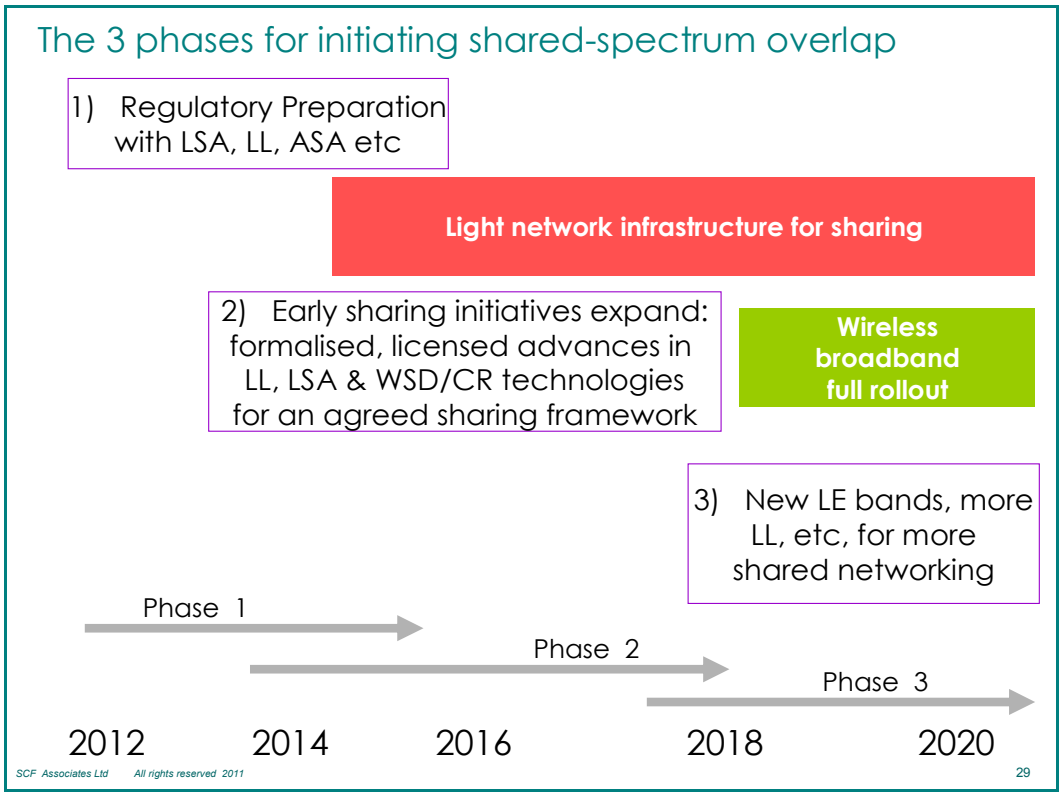
*First Phase - prepare for the future:* Regulatory bodies prepare, with the end users and stakeholders, in the EU and globally, for new approaches to spectrum management through more sharing within formalized structures. This implies NRAs working together on a common framework for the expansion of spectrum sharing, while addressing practical concerns about interference with monitoring technologies and practices. A strong effort in liaison is needed involving both the incumbents and potential new entrants, perhaps through a ginger group of representatives from all sectors, including end-users.

*Second Phase - endorse the operational framework for a new sharing regime*: Set up the practical bodies and rules to move Member States towards the new regime over a set timeframe.

*Third Phase - embrace the opportunities*: new types of network operation with sharing in the public space (public and user-defined/operated networks) and the regulatory support required for new LE bandwidth, more light licensing, exploitation of white spaces for wireless broadband, etc. It is well to note that we may see market pressures for more rapid deregulation, if some new players, eg from the Internet and consumer electronics industries assert their policy preferences, and if developments in 'social networking' and user-based organizations force the pace of change – so that the speed of WRC/ITU processes come under pressure.

In summary, an agenda and a schedule for moving forward are as follows:

Figure 5.1. A three-phase roll out for increased spectrum sharing



# List of abbreviations

| | |
|---|---|
| AIP | Administered Incentive Pricing |
| ASA | Authorised Shared Access |
| BEM | Block Edge Mask |
| BOM | Bill Of Materials |
| CEPT | Conférence Européenne des Administrations des Postes et des Télécommunications |
| CR | Cognitive Radio |
| CRS | Cognitive Radio System |
| CSCEWS | Computer, Software, Consumer Electronics And Web Services (sector) |
| CT | Cognitive Technologies |
| CUG | Closed User Group |
| CUS | Collective Use of Spectrum |
| DAA | Detect and Avoid |
| DFS | Dynamic Frequency Selection |
| DAE | Digital Agenda for Europe |
| DSSS | Direct-Sequence Spread Spectrum |
| DTT | Digital Terrestrial Television |
| ECC | European Communications Committee |
| ECO | European Communications Office |
| ETSI | European Telecommunications Standards Institute |
| EU | European Union |
| FCC | Federal Communications Commission |
| FHSS | Frequency-Hopping Spread Spectrum |
| FO | Fibre Optic |
| FP7 | Seventh Framework Programme |
| GEO | Geo- Stationary Orbit (satellite) |
| HALES | High Altitude Long Endurance Systems |
| IEEE | Institute of Electrical & Electronics Engineers |
| IMT | International Mobile Telecommunications |
| IPTV | Internet Protocol Television |
| ISO | International Organization for Standardization |
| ISP | Internet Service Provider |
| ITS | Intelligent Transport Systems |

| | |
|---|---|
| ITU | International Telecommunication Union |
| LSA | Licensed Shared Access |
| LBT | Listen Before Transmit |
| LE | Licence Exempt |
| LEO | Low Earth Orbit (satellite) |
| LTE | 3G Long Term Evolution |
| M2M | Machine to Machine |
| MEO | Medium Earth Orbit (satellite) |
| MFN | Multi Frequency Network |
| MNO | Mobile Network Operator |
| MS | Member States |
| NRA | National Regulatory Authority |
| PAMR | Public Access Mobile Radio |
| PMSE | Programme Making and Special Event |
| PMR | Private Mobile Radio |
| QoS | Quality of Service |
| R&TTE | Radio and Telecommunications Terminal Equipment |
| RATs | Radio Access Technologies |
| RFID | Radio Frequency Identification |
| RLAN | Radio Local Area Network |
| RSPG | Radio Spectrum Policy Group |
| RSPP | Radio Spectrum Policy Programme |
| SDR | Software Defined Radio |
| SRD | Short Range Device |
| SRR | Short Range Radar |
| SSO | Shared Spectrum Operator |
| SUS | Shared Use of Spectrum |
| UAP | Universal Access Point |
| UHF | Ultra High Frequency |
| UMTS | Universal Mobile Telecommunications System |
| UWB | Ultra Wide Band |

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http://www.itu.int/osg/spu/stn/spectrum/workshop_proceedings/Background_Papers_Final/Michale%20Whittaker%20-%20space_centric_management_spu(mjw).pdf

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# APPENDICES

# Appendix A: Organizations consulted

| Name | Organization | Country |
|---|---|---|
| Franz Ziegelwanger | Federal Ministry for Transport, Innovation and Technology | Austria |
| Gino Ducheyne | Belgian Institute for Postal Services and Telecommunications (BIPT) | Belgium |
| Vyara Mincheva | Communications Regulation Commission (CRC) | Bulgaria |
| Anastasios Elia | Department of Electronic Communications, Ministry of Communications and Works | Cyprus |
| Karel Antousek | Czech Telecommunication Office | Czech Republic |
| Henning Blume Andersen | National IT and Telecom Agency | Denmark |
| Irena Lukas | Technical Surveillance Authority | Estonia |
| Margit Huhtala | Finnish Communications Regulatory Authority (FICORA) | Finland |
| Jean-Yves Montfort | Agence Nationale des Fréquences (ANFR) | France |
| Karsten Buckwitz | Bundesnetzagentur | Germany |
| Michael Kraemer | E-Plus Mobilfunk/ ITU Working Party 5D - IMT Systems | Germany |
| Karl-Heinz Laudan | Deutsche Telekom | Germany |
| Nadia Katsanou | Hellenic Telecommunications and Post Commission (EETT) | Greece |
| János Grad | National Media and Infocommunications Authority | Hungary |
| Kenneth Concannon | Commission for Communications Regulation (ComReg) | Ireland |
| Mario Tagiullo | Autorità per le Garanzie nelle Comunicazioni (Agcom) | Italy |
| Vitolds Vaznis | Electronic Communications Office | Latvia |
| Kotryna Raščiūtė | Communications Regulatory Authority (RRT) | Lithuania |
| Roland Thurmes | Institut Luxembourgeois de Régulation (ILR) | Luxembourg |
| Adrian Galea | Malta Communications Authority | Malta |
| Lilian Jeanty | Radio Communications Agency Netherlands | Netherlands |

| | | |
|---|---|---|
| Wiktor Sęga | Office of Electronic Communications (UKE) | Poland |
| Jaime Afonso | Autoridade Nacional de Comunicacoes (ANACOM) | Portugal |
| Jozef Kertes | Telecommunications Regulatory Authority of the Slovak Republic (TUSR) | Slovakia |
| Marjan Trdin | Agency for post and electronic communications of the Republic of Slovenia (APEK) | Slovenia |
| Antonio Fernández-Paniagua | Ministerio de Industria, Turismo y Comercio | Spain |
| Ramon Roca | Guifi.net | Spain |
| Dejan Jaksic, Jonas Wessels | National Post and Telecom Agency (PTS) | Sweden |
| Alexandre Kholod | BAKOM/ CEPT SE 43 | Switzerland |
| Tom Phillips, John Giusti | GSMA | United Kingdom |
| John Cavanagh, Paul Chapman | Office of Communications (Ofcom) | United Kingdom |
| Peter Harrop | IDTechEx Ltd | United Kingdom |
| Martin Cave | Imperial College Business School | United Kingdom |

# Appendix B: List of relevant FP7 projects

The following FP7 projects received our survey form. Those marked with an asterix completed and returned it:

| | | |
|---|---|---|
| ACROPOLIS | | Advanced Coexistence technologies for Radio OPtimisatiOn in LIcenced and unlicensed Spectrum (Network of Excellence on Cognitive Communications) http://www.ict-acropolis.eu/ |
| ALARP | | Railway track automatic warning system based on distributed personal mobile terminals) http://www.alarp.eu/ |
| ALPHA | * | Architectures for fLexible Photonic Home and Access network http://www.ict-alpha.eu/ |
| AMIMOS | * | Agile MIMO systems for communications, biomedicine, and defense http://www.kth.se/ees/omskolan/organisation/avdelningar/sp/research/projects/amimos |
| ARAGORN | * | Adaptive Reconfigurable Access and Generic Interfaces for Optimization in Radio Networks http://www.ict-aragorn.eu/ |
| ARTIST4G | * | Advanced Radio Interface Technologies for 4G Systems https://ict-artist4g.eu/ |
| ASPIS | | Autonomous Surveillance in Public transport Infrastructure Systems http://www.aspis-project.eu/ |
| ASTRONET | * | Coordinating strategic planning for European Astronomy http://www.astronet-eu.org/ |
| BeFEMTO | | Broadband Evolved FEMTO Networks http://www.ict-befemto.eu/ |
| BUNGEE | * | Beyond Next Generation Mobile Broadband http://www.ict-bungee.eu/ |
| C2POWER | | Cognitive radio and Cooperative strategies for POWER saving in multi-standard wireless devices http://www.ict-c2power.eu |
| CARE | | Coordinating the Antenna Research in Europe http://www.antennasvce.org/Community/Dissemination?action=area_view&id_area=35 |
| CARMEN | * | CARrier grade MEsh Networks http://www.ict-carmen.eu |
| CODIV | | Enhanced Wireless Communication Systems Employing COoperative DIVersity http://www.ict-codiv.eu/ |
| CHOSEN | * | Cooperative hybrid objects in sensor networks http://www.chosen.eu/ |
| COGEU | * | COgnitive radio systems for efficient sharing of TV white spaces in EUropean context http://www.ict-cogeu.eu/ |
| COMCOM | | Communication and Computation - Two Sides of One Tapestry |
| CONECT | | Cooperative Networking for High Capacity Transport Architectures http://www.conect-ict.eu/ |
| CONET | | Cooperating objects Network of excellence http://www.cooperating-objects.eu/ |

| | | |
|---|---|---|
| CONSERN | | Cooperative and Self growing Energy aware Networks<br>https://www.ict-consern.eu/ |
| CREW | | Cognitive Radio Experimentation World<br>http://www.crew-project.eu/ |
| CROWN | | Cognitive radio oriented wireless networks<br>http://www.fp7-crown.eu/ |
| DARWIN | | Deep mm-Wave RF-CMOS integrated circuits |
| DAVINCI Codes | | Design and Versatile Implementation of Non-binary wireless Com-munications based on Innovative LDPC Codes<br>http://www.ict-davinci-codes.eu/ |
| E3 | | End-to-End Efficiency<br>https://ict-e3.eu/ |
| E-BRAINS | | Best-Reliable Ambient Intelligent Nano Sensor Systems<br>http://www.e-brains.org/ |
| EU-MESH | | Enhanced, Ubiquitous and dependable broadband access using MESH networks<br>http://www.eu-mesh.eu/ |
| EUWB | | Coexisting short range radio by advanced ultra-wideband radio technology<br>http://www.euwb.eu/ |
| EXALTED | * | EXpAnding LTE for Devices<br>http://www.ict-exalted.eu/ |
| FARAMIR | | Flexible and spectrum-Aware Radio Access through Measurements and modelling in cognitive Radio systems<br>http://www.ict-faramir.eu/ |
| FEEDNETBACK | | Feedback design for wireless networked systems<br>http://www.feednetback.eu/ |
| FIEMSER | * | Friendly Intelligent Energy Management System for Existing Residential Buildings<br>http://www.fiemser.eu/ |
| FIVER | * | Fully-converged quintuple-play integrated optical-wireless access architectures<br>http://www.ict-fiver.eu/ (nb link broken) |
| FLAVIA | * | FLexible Architecture for Virtualizable wireless future Internet Access<br>http://www.ict-flavia.eu/ |
| FLEXWARE | | Flexible wireless automation in real-time environments<br>http://www.flexware.at/ |
| FLEXWIN | * | FLEXible microsystem technology for micro- and millimetre-wave antenna arrays With INtelligent pixels<br>www.flexwin.eu/ |
| FREEDOM | | Femtocell-based netwoRk Enhancement by intErference managEment and coorDination of infOrmation for seaMless connectivity<br>http://www.ict-freedom.eu/ |
| FUTON | | Fibre-Optic Networks for Distributed Extendible Heterogeneous Radio Architectures and Service Provisioning<br>http://www.ict-futon.eu/ |
| GENESIs | | Green sEnsor NEtworks for Structural monitoring<br>http://genesi.di.uniroma1.it/ |
| GINSENG | | Performance control in wireless sensor networks<br>http://www.ict-ginseng.eu/ |
| GOSPEL | * | Governing the speed of light<br>http://www.gospel-project.eu/Web/index.php |
| HURRICANE | * | Handovers for Ubiquitous and optimal broadband Connectivity Among cooperative Networking Environments http://www.ict-hurricane.eu/ |
| INESS | * | INtegrated European signalling system<br>http://www.iness.eu/ |
| INTEGRIS | | INTelligent Electrical Grid Sensor communications<br>http://fp7integris.eu/ |
| IPHOS | * | Integrated photonic transceivers at sub-terahertz wave range for ultra-wideband wireless communications<br>http://www.iphos-project.eu/project_overview |

| | | |
|---|---|---|
| LOFAR-AUGER | * | From black holes to ultra-high energy cosmic rays: exploring the extremes of the universe with low-frequency radio interferometry |
| LOLA | | Achieving low-latency in wireless communications<br>http://www.ict-lola.eu/ |
| MACALO | * | Magneto Caloritronics |
| MAKESENSE | * | Easy Programming of Integrated Wireless Sensor Networks<br>http://www.project-makesense.eu/ |
| MEDIEVAL | | MultimEDia transport for mobIlE Video AppLications<br>http://www.ict-medieval.eu/ |
| MEMS-4-MMIC | * | Enabling MEMS-MMIC technology for cost-effective multifunctional RF-system integration<br>http://www.mems4mmic.com/ |
| MIMAX | * | Advanced MIMO Systems for MAXimum Reliability and Performance<br>http://www.ict-mimax.eu/ |
| MOBESENS | * | Mobile water quality sensor system<br>http://www.mobesens.eu/ |
| MOBISERV | | An integrated intelligent home environment for the provision of health, nutrition and mobility services to the elderly |
| MONET | | Mechanisms for Optimization of hybrid ad-hoc NETworks and satellite networks<br>http://monet.tekever.com/ |
| MOSQUITO | | Mobile software and services, Standardisation, Quality, Interoperability, Testing, Open source<br>http://www.mosquito-fp7.eu/ |
| MULTI-BASE | | Scalable multi-tasking baseband for mobile communications<br>http://www.multibase-project.eu/ |
| MUSCADE | | Multimedia Scalable 3D for Europe<br>http://www.muscade.eu/ |
| MUTIVIS | | Multispectal terahertz, infrared, visible imaging and spectroscopy<br>http://www.mutivis-ict.eu/ |
| Net!Works | | European Technology Platforum<br>http://www.networks-etp.eu/ |
| NEWCOM++ | | Network of Excellence in Wireless Communications<br>http://www.newcom-project.eu/ |
| N-CRAVE | * | Network Coding for Robust Architectures in Volatile Environments<br>http://www.n-crave.eu/ |
| NOWIRE | | Network Coding for Wireless Networks<br>http://www.epfl.ch |
| OFELIA | * | Open Flow in Europe: Linking Infrastructure and Applications<br>http://www.fp7-ofelia.eu/ |
| OMEGA | * | Home Gigabit Access<br>http://www.ict-omega.eu/ |
| OneFIT | * | Opportunistic networks and Cognitive Management Systems for Efficient Application Provision in the Future InterneT<br>http://www.ict-onefit.eu/ |
| OPNEX | * | Optimization driven multi-hop network design and experimentation<br>http://www.opnex.eu/ |
| ORICLA | | Towards Electronic Product Coding with RFID tags based on hybrid organic-oxide complementary thin-film technology<br>https://projects.imec.be/oricla/ |
| OVERSEE | * | Open VEhiculaR SEcurE platform<br>https://www.oversee-project.com/ |
| PD-NET | | Towards Future Pervasive Display Networks<br>http://pd-net.org/ |
| PECES | | Pervasive computing in embedded systems<br>https://peces.nes.uni-due.de/ |
| PHYDYAS | * | PHYsical layer for DYnamic spectrum AccesS and cognitive radio<br>http://www.ist-phydyas.org/ website taken offline |

| | | |
|---|---|---|
| PLANET | | PLAtform for the deployment and operation of heterogeneous NETworked cooperating objects<br>http://planet.etra-id.com/ |
| POBICOS | * | Platform for opportunistic behaviour in incompletely specified, heterogeneous object communities<br>http://www.ict-pobicos.eu/ |
| POCEMON | | Point-of-care monitoring and diagnostics for autoimmune diseases<br>http://www.pocemon.eu/ |
| PRECISIO | | Professional Receiver via Software Radio<br>http://www.nsl.eu.com |
| PREPSKA | | A PREparatory phase Proposal for the Square Kilometre Array<br>http://www.jb.man.ac.uk/prepska/ |
| PRIAM | * | Printable functionalities for truly autonomous, intelligent lighting and signalling systems<br>http://www.priam-project.eu/ |
| PULSERS2 | | Pervasive Ultra-wideband Low Spectral Energy Radio Systems -Phase II<br>http://www.pulsers.eu/ |
| QoSMOS | | Quality of Service and MObility driven cognitive radio Systems<br>http://www.ict-qosmos.eu/ |
| QUASAR | | Quantitative Assessment of Secondary Spectrum Access<br>http://www.quasarspectrum.eu/ |
| RADIONET-FP7 | | Advanced radio astronomy in Europe<br>http://www.radionet-eu.org/ |
| REWIND | * | Relay based WIreless Network and standard<br>http://www.rewind-project.eu/ |
| ROCKET | | Reconfigurable OFDMA-based Cooperative NetworKs Enabled by Agile SpecTrum Use<br>http://www.ict-rocket.eu/ |
| ROOTHZ | * | Semiconductor nanodevices for room temperature THz emission and detection<br>http://www.roothz.eu/?q=node/1 |
| ROSE | | Robust sensor array processing<br>http://lib.bioinfo.pl/projects/view/1480 |
| SACRA | * | Spectrum and energy efficiency through multi-band cognitive radio<br>http://www.ict-sacra.eu/ |
| SAIL | * | Scalable & Adaptive Internet solutions<br>http://www.sail-project.eu/ |
| SAMURAI | * | Spectrum Aggregation and Multi-User MIMO: Real-world Impact<br>http://www.ict-samurai.eu/ |
| SANDRA | | Seamless aeronautical networking through integration of data links, radios, and antennas<br>http://www.ctit.utwente.nl/research/projects/international/fp7-ip/sandra.doc/ |
| SAPHYRE / | * | Sharing physical resources – mechanisms and implementations for wireless networks<br>http://www.saphyre.eu |
| SAVE ME | | System and Actions for VEhicles and transportation hubs to support Disaster Mitigation and Evacuation<br>http://www.save-me.eu/ |
| SCAMPI | | Service platform for social Aware Mobile and Pervasive computIng<br>http://www.ict-scampi.eu/ |
| SELECT | | Smart and Efficient Location, idEntification, and Cooperation Techniques<br>http://www.selectwireless.eu/home.asp |
| SENDORA | | SEnsor Network for Dynamic and cOgnitive Radio Access<br>http://www.sendora.eu/ |
| SENSEI | | Integrating the Physical with the Digital World of the Network of the Future<br>http://www.sensei-project.eu/ |
| SKYMEDIA | | UAV-based capturing of HD/3D content with WSN augmentation, real-time processing and immaterial rendering for immersive media experiences<br>http://ict-skymedia.eu/skymedia/ |

| | | |
|---|---|---|
| SMARTFIBER | | Miniaturised Structural Monitoring System with Autonomous Readout Micro-Technology and Fiber sensor network<br>http://www.imec.be/flame/ |
| SMART-NET | | SMART-antenna multimode wireless mesh Network<br>https://www.ict-smartnet.eu/ |
| SOCRATES | * | Self-Optimisation and self-configuration in wireless networks<br>http://www.fp7-socrates.org |
| SPITFIRE | * | Semantic-Service Provisioning for the Internet of Things using Future Internet Research by Experimentation<br>http://spitfire-project.eu/ |
| SUCCESS | | Silicon-based Ultra-Compact Cost-Efficient System Design for mm-Wave Sensors<br>http://www.success-project.eu/ |
| TIBUCON | | Self Powered Wireless Sensor Network for HVAC System Energy Improvement - Towards Integral Building Connectivity<br>http://www.tibucon.eu/ |
| TOSCA | | Terahertz Optoelectronics - From the Science of Cascades to Applications<br>http://www.leeds.ac.uk |
| TREND | | Towards Real Energy-efficient Network Design (Network of Excellence)<br>http://www.fp7-trend.eu/ (nb link broken) |
| TUMESA | | MEMS TUneable MEtamaterials for Smart wireless Applications<br>http://radio.tkk.fi/tumesa/ |
| TWISNET | | Trustworthy Wireless Industrial Sensor networks<br>http://www.twisnet.eu/ |
| UCELLS | * | Ultra-wideband real-time interference monitoring and CELLular management Strategies<br>http://www.ist-ucells.org/ |
| ULOOP | * | User-centric Wireless Local-Loop<br>http://uloop.eu/ |
| VISION | | Video-oriented UWB-based Intelligent Ubiquitous Sensing<br>http://www.vision-ercproject.eu/ |
| VITRO | | Virtualized dIstributed plaTfoRms of smart Objects<br>http://www.vitro-fp7.eu/ |
| WALTER | | Wireless Alliance for Testing Experiment and Research<br>http://www.walter-uwb.eu/ |
| WHERE2 | | Wireless Hybrid Enhanced Mobile Radio Estimators - Phase 2<br>http://www.ict-where2.eu/ |

# Appendix C: Protected/prohibited bands

**Search/rescue and distress calling channels:**

| | | |
|---|---|---|
| 500 kHz | 6268 kHz | 14.993 MHz |
| 2174.5 kHz | 6312 kHz | 16.695 MHz |
| 2182 kHz | 8364 kHz | 16.804.5 MHz |
| 2187.5 kHz | 8376.5 kHz | 19.993 MHz |
| 3023 kHz | 8414.5 kHz | 121.5 MHz |
| 4177.5 kHz | 10.003 MHz | 156.8 MHz |
| 4207.5 kHz | 12.520 MHz | 243 MHz |
| 5680 kHz | 12.577 MHz | |

**Time/frequency standard channels:**

| | | |
|---|---|---|
| 14 - 19.95 kHz | 4.995 - 5.005 MHz | 19.990 - 20.010 MHz |
| 20.05 - 70 kHz | 9.995 - 10.005 MHz | 24.990 - 25.010 MHz |
| 2.498 - 2.505 MHz | 14.990 - 15.010 MHz | |

**Emergency beacons for rescue (earth-space Mobile satellite):**

406-406.1 MHz

**Radio astronomy, earth observation and space research:**

| | | |
|---|---|---|
| 1400 - 1427 MHz | 50.2 - 50.4 GHz | 164 - 167 GHz |
| 2690 - 2700 MHz | 52.6 - 54.25 GHz | 182 - 185 GHz |
| 10.68 - 10.7 GHz | 86 - 92 GHz | 190 - 191.8 GHz |
| 15.35 - 15.4 GHz | 100 - 102 GHz | 200 - 209 GHz |
| 23.6 - 24 GHz | 109.5 - 111.8 GHz | 226 - 231.5 GHz |
| 31.3 - 31.5 GHz | 114.25 - 116 GHz | 250 - 252 GHz |
| 48.94 - 49.04 GHz | 148.5 - 151.5 GHz | |

# Appendix D: Community Wireless Networks in Europe

CONFINE — Community Networks Testbed for the Future Internet (FP7 project) — http://confine-project.eu/

**Austria**
Funkfeuer, Vienna, Graz, Bad Ischl — http://www.funkfeuer.at
LZB-Net, Hofkichen — http://www.lanzenberg.at
Funkfeuer Wels, Wels — http://wels.funkfeuer.at
Funkfeuer Linz, Linz — http://linz.funkfeuer.at
Funkfeuer Traunviertel, Traunviertel in OÖ — http://traunviertel.funkfeuer.at
Funkfeuer Salzkammergut, Salzkammergut — http://salzkammergut.funkfeuer.at/

**Belgium**
ReseauCitoyen, Brussels — http://www.reseaucitoyen.be/wiki
WirelessAntwerpen, Antwerp — http://www.wirelessantwerpen.be
WirelessBelgie, Belgium — http://www.wirelessbelgie.be
WirelessGent, Belgium — http://www.wirelessgent.be
WirelessBrussel, Belgium — http://www.wirelessbrussel.be
WirelessLeuven, Belgium — http://www.wirelessleuven.be
WirelessBrugge, Belgium — http://www.wirelessbrugge.be
WirelessBlankenberge, Belgium — http://www.wirelessblankenberge.be

**Bosnia and Herzegovina**
wireless.ba, United wireless communities in Bosnia — http://www.wireless.ba
wireless.rs.ba, United wireless communities in Republic of Srpska — http://www.wireless.rs.ba
saWireless, Sarajevo — http://sa.wireless.ba
Viwa net, Visoko — http://vi.wireless.ba
NEON Solucije, Kalesija — http://www.neon.ba
BLwireless, Banjaluka — http://www.blwireless.net
BDB@wireless, Banja Luka — http://www.bdb.rs.ba
mo-wireless, Mostar — http://mo.wireless.ba
LPwireless, LP — http://www.lpwireless.net
BNWireless, Bijeljina, http://www.bnwireless.net
NeumWIRELESS, Neum — http://www.neumwireless.org

**Czech Republic**
CZFree.Net, Czech Republic — http://www.czfree.net/
Czela.net, Čelákovice, Czech Republic — http://www.czela.net
HKFree.org, Hradec Králové, Czech Republic — http://www.hkfree.org
KLFree.Net, Kladno, Czech Republic — http://www.klfree.net
LBCFree.net, Liberec, Czech Republic — http://www.lbcfree.net
PilsFree.net, Plzeň, Czech Republic — http://www.pilsfree.net
UNHFree.net, Unhošť, Czech Republic — http://www.unhfree.net
KHnet.info, Kutná Hora, Czech Republic — http://www.khnet.info
mh2net, Mnichovo Hradiště, Czech Republic — http://www.mh2net.cz
Evkanet, Ostrava, Czech Republic — http://www.evkanet.net

CZF-Praha, Prague, Czech Republic — http://www.czf-praha.net
Krivonet, Křivoklátsko, Czech Republic — http://www.krivonet.info/
JM-Net, Prague, Czech Republic — http://www.jmnet.cz/
SLFree.Net, Slavičín, Czech Republic — http://www.slfree.net/
Other important Czech community networks:
Gavanet, Varnsdorf, Czech Republic — http://www.gavanet.org
AirDump.Net, ACzW, Czech &mdash — Wireless Community
NobodyNet, Holýšov, Czech Republic — http://www.nobody-network.net
PVFree.Net, Prostějov, Czech Republic — http://www.pvfree.net
Svobodna Praha, Czech Republic — http://www.svobodna-praha.net

**Croatia**
Map of Croatian Wireless Networks, — http://www.mreze.org/
Croatian Wireless Association, — http://www.hrfreenet.hr/
VGWireless, Velika Gorica — http://www.vgwireless.hr/
RiWireless, Rijeka — http://www.riwireless.net/
Dugave Wireless, Dugave, Zagreb — http://www.dugave.net/
PUWireless, Pula, Zagreb — http://www.pulawireless.hr/
BSWireless, Baška, Krk — http://www.bswireless.net/
BKWireless, Bakar — http://www.bkwireless.com/
DJWireless, Đakovo — http://www.djw.hr/
KAWireless, Karlovac — http://www.kawireless.hr/
VRWireless, Vrbovec — http://www.vrw.hr/
ZBWireless, Zabok — http://www.zabok-wireless.hr/
ZDWIreless, Zadar — http://www.zdwireless.hr/
WirelessKZ, Krizevci — http://www.wirelesskz.net/
ZGWireless, Zagreb — http://www.zgwireless.net/
Međimurje Wireless, Čakovec — http://www.mwireless.hr/
Extreme Wireless, Varaždin — http://www.extremewifi.hr/
OSWireless, Osijek — http://www.oswireless.hr/
ZNET, Zagreb — http://www.znetonline.net/
WiFiHR, Zagreb - Vrbovec — http://www.wifihr.net/

**Denmark**
DIIRWB, Djurslands International Institute of Rural Wireless Broadband — http://www.diirwb.net/

**Finland**
OpenSpark — https://open.sparknet.fi/

**France**
Fédération France Wireless — http://www.wireless-fr.org/
List of French community, — http://www.wireless-fr.org/spip/article.php3?id_article=8
Lille sans fil — http://lillesansfil.org/
Wifi Montauban, France — http://www.wifi-montauban.net/
Toulouse Sans Fil, Wifi Toulouse — http://www.toulouse-sans-fil.net/
Rural Area Networks Webring, http://ran.vaour.net/cgi-bin/ringlink/list.pl?ringid=ran

**Germany**
Freifunk Augsburg, wireless community in Augsburg, Germany — http://augsburg.freifunk.net/
Freifunk.net, Berlin a.o., Germany — http://www.freifunk.net/
Freifunk Bochum, Bochum, Germany — http://freifunk.das-labor.org/
Freifunk Brandenburg, Brandenburg an der Havel, Germany — http://www.freifunk-brb.de
Förderverein Bürgernetz Dresden e.V., Dresden, Germany — http://www.fbn-dd.de/
Freifunk Halle, wireless community in Halle, Germany — http://halle.freifunk.net/
Freifunk Koeln, wireless community in Cologne, Germany — http://www.freifunk-koeln.de
Freifunk Leipzig, wireless community in Leipzig, Germany — http://leipzig.freifunk.net/
Freifunk Moers, Freifunk in Moers, Germany —

http://dasinter.net/ffmoers/
Freifunk Oldenburg, Freifunk in Oldenburg, Germany —
http://freifunk-ol.de/
OpenNet Initiative, Rostock, Germany —
http://www.opennet-initiative.de/
Freifunk Potsdam, wireless community in Potsdam, Germany —
http://www.freifunk-potsdam.de/
Freifunk-Ruhrstadt.de, Zone of the Ruhrstadt, Germany —
http://www.freifunk-ruhrstadt.de/
Freifunk Weimar, wireless community in Weimar, Germany —
http://wireless.subsignal.org/

**Greece**
Wireless Networks Association, National — http://www.wna.gr/
Athens Wireless Metropolitan Network, Athens — http://www.awmn.net/
Cyclades Wireless Network, Cyclades — http://cywn.dyndns.org/
Heraklion Student Wireless Network, Heraklion —
http://wireless.uoc.gr/
Patras Wireless Network, Patras — http://www.patraswireless.net/
Wireless Agrinio Network, Agrinio — http://www.wiran.gr/
Patras Wireless Metropolitan Network, Patras Patras Wirless
Metropolitan Network
WANA, Amalias — http://www.wana.gr/
Imathias Wireless Metropolitan Network, Imathia —
http://www.iwmn.net/
Wireless Network of Korinth, Korinthia — http://wnk.awmn.net/
Messinia Wireless Network, Messina — http://kalamata.homelinux.com/

**Hungary**
Hungarian Wireless Community, Budapest — http://www.huwico.hu/

**Ireland**
IrishWAN, All-Ireland community radio project —
http://www.irishwan.ie.

**Italy**
Ninux.org, Rome, IT — http://www.ninux.org/
eigenNet, Pisa, IT — http://www.eigenlab.org/
NECO, Vietri di Potenza (PZ), IT — http://www.progettoneco.org
Luna, Trento, Rovereto, Riva del Garda (TN) , IT —
http://www.futur3.it/rete-luna/

**Macedonia**
Skopje Wireless Community, Skopje — http://www.skopjewifi.com
Macedonian Wireless Community, Macedonia —
http://www.wifimacedonia.net

**Netherlands**
Wireless Leiden, Leiden, Netherlands —
http://www.wirelessleiden.nl/en/ and http://wiki.wirelessleiden.nl/
(Wiki in dutch)

**Portugal**
Movimento Wireless Português — http://wireless.com.pt/
nazamesh.net— (merged with Unimos — http://unimos.net)
Unimos — http://unimos.net
MVNet Wireless wiki http://moitasvenda.net/wireless, Moitas Venda,
Portugal

**Poland**
Outernet — http://outernet.pl/

**Serbia**
BG Wireless, Belgrade — http://www.bgwireless.net
NS Wireless, Novi Sad — http://www.nswireless.org
VAWireless, Valjevo — http://www.vawireless.rs

Uzice bez zice, wireless community, Uzice — http://wireless.uzice.net
SuWireless, Subotica — http://www.suwireless.org
WirelessAR, Arandjelovac — http://www.arandjelovcani.com
Kruševac Open, Kruševac — http://www.krusevacopen.net
Titel Mreza, Titel — http://www.titelskibreg.org

**Slovakia**
SKFree.Net, Slovakia — http://www.skfree.net/

**Slovenia**
kiberpipa.net, Ljubljana — http://kiberpipa.net
wlan ljubljana, Ljubljana — http://wlan-lj.net

**Spain**
RedLibre — http://www.redlibre.net/
Guifi.net — http://www.guifi.net

**Sweden**
Ipredia — http://ipredia.se/wiki/Huvudsida

**Switzerland**
www.openwireless.ch, Bern — http://www.openwireless.ch/

**United Kingdom**
Neoeon, Holderness & Humber, UK — http://www.neoeon.com/
piertopier.net, Brighton, UK — http://www.piertopier.net/
Bristol Wireless, Bristol, UK — http://www.bristolwireless.net/
Kings Hill Wireless, Kings Hill, Kent, UK — http://www.kingshill.quickanet.com/
QuickaNet Broadband, United Kingdom, UK — http://www.quickanet.com/
Cambridge Matrix, Cambridge, UK — http://www.cambridgematrix.co.uk/
South Witham Broadband, Lincolnshire, UK — http://wireless.southwitham.net/
Consume the Net, London, UK — http://consume.net/
free2air, London, UK — http://www.free2air.org/
gmap, London, UK — http://londonist.com/2007/05/free_wifi_in_lo.php/
Lancaster Mesh, Lancaster, UK — http://www.lancastermesh.co.uk/
Manchester Wireless, Manchester, UK — http://www.manchesterwireless.net/
TottonWireless.net, Totton, UK — http://tottonwireless.net/
Boundless, Deptford, London, UK — http://boundless.coop/
WLAN ORG UK, original ww promoting site — http://www.wlan.org.uk/
Airzone Broadband, Essex, UK — http://www.airzone.net/
SOWN, Southampton, UK — http://www.sown.org.uk/
RHBMesh North Yorkshire, UK - http://rhbmesh.net
WiFi Foundation, London, UK - http://www.wififoundation.org/

# Appendix E: Final workshop report

## How can we promote the shared use of radio spectrum resources in Europe?

## Brussels 16 December 2011

A workshop to present the findings of the study was held in Brussels, with over 150 stakeholders attending. The workshop was introduced by Pearse O'Donohue, Head of Unit, Radio Spectrum Policy, who explained the purpose of the workshop: to discuss the findings of the draft report of the independent study team and allow ample time for stakeholders to give their views. This would allow the consultants to complete their report, taking into account the views of stakeholders. The role of the Commission was to act as facilitator.

The workshop was divided into three sessions – first, a presentation on the study's findings; second, the recommendations emerging from the study; and finally an open discussion. Interested parties were invited to provide input to the workshop in response to four questions, which provided a structure for the open discussion. These questions were:

(1) How can technologies that already use shared access spectrum, such as Wi-Fi, help to achieve the European targets for wireless broadband (including speed and coverage)?

(2) In addition to Wi-Fi, there are also other applications – such as short-range devices (SRD), intelligent transport systems (ITS) or smart meters – that rely on the use of shared spectrum. Is there sufficient spectrum available in the EU that can be accessed on a shared basis to address the growing need for wireless connectivity? If not, what are the key bottlenecks?

(3) How can the present state of the art of adaptive radio access technologies (such as cognitive radio, software defined radio, MIMO, phased arrays etc.) help to share spectrum more efficiently?

(4) Does spectrum sharing always require licence-exempt access or is there also a need for more sharing based on a licensed regime? If so, what are the opportunities and incentives, also for existing spectrum users?

Submissions in response to these questions were received from the following organizations and individuals:

abertis telecom

ANFR

Cisco

COGEU

Deutsche Telekom

ESB Networks

Global University System

International Association of Public Transport (UITP)

Motorola

Nokia

Nokia Siemens Networks

Public Safety Communication Europe

SAPHYRE

Sennheiser

Silver Spring Technology

SpectrumConsult

Wroclawskie Centrum Badań EIT

These submissions were taken into account in the preparation of the final study report.

### Session 1: Findings

The study's main findings were presented in the first session, after which the following points of clarification and comments were made:

- A question was raised about ASA applied to government: ie did the study look at sharing of military spectrum by civilian services for emergency, public safety etc.?
- The interpretation of ASA as being mainly for cellular to cellular sharing was questioned. The original concept and its presentation at various meetings earlier in 2011 was about sharing of spectrum by an incumbent, eg military, with commercial sector secondary users.
- This view was emphasized by another delegate, who said that ASA supports more sharing of licensed spectrum and we need more spectrum. However with government primary users there may be issues of security and it could be a long process to reach agreements. Sharing could also be between public sector users with the same rights of use. RSPG definitions for CUS and LSA are useful but should be kept separate.
- Another view was that ASA was a more voluntary approach to leasing and sharing. But will we see more opportunities for regulators to impose mandatory decisions on sharing?
- The potential role for white space in the UHF band was mentioned. Although there are some difficulties, eg with PMSE, there are positive developments. Also it is important to track developments in other parts of the world – the USA, for example - to ensure that the EU does not fall behind.
- Even in rural areas we will need technical conditions for sharing and these have yet to be defined.
- Wi-Fi is popular but there is 483 MHz at 5 GHz available – is there a need for more? Unlicensed is possible above 5 GHz.
- A plea was made for specific frequencies to be allocated globally for applications such as intelligent transport systems, ideally in the 5 GHz band.

- The efficiency of Wi-Fi can be as low as 2% owing to dropped packets, resends, and general packet overheads.
- We need licensed spectrum. We need exclusive spectrum. We need reliability and safety. Leasing gives opportunities for time-based sharing.
- Mention was made of Ofcom UK's proposals at 2.6 GHz, although not on an LE basis, where there could be as many as 10 licensees using low power devices.
- The final comment on the session 1 presentation was that what was needed was not more spectrum but new business models for exploiting it.

### Session 2: Recommendations

In the second session, which included a detailed explanation of the scenario and economic modelling aspects of the study and the subsequent recommendations, the following points were made:

- One delegate remarked that doing such studies is difficult, particularly capturing the net benefits of wireless, and taking into account substitution issues
- Another delegate supported the analysis of problems and the process put forward, but disagreed with the formulation for Scenario 3. LE spectrum of 2 x 50MHz is not enough. With new Wi-Fi standards featuring channels 160 MHz wide for 1 Gbps transfers of multiple HD video streams in enterprise and carrier grade networks, this won't be enough. Spectrum is not available in the UHF band so there is a case for making 5 GHz a contiguous LE band – ie, by making the 5350-5470 MHz gap between the existing LE bands licence-exempt, too. But this is for urban areas requiring dense deployments and high capacity, rather than a solution for rural areas.
- If Scenario 3 were to come to fruition, who would invest in the networks in these LE bands? A number of different models are now emerging, eg from municipalities offering free Wi-Fi to user-owned infrastructure developments (eg Guifi.net) to retail outlets attracting customers by offering free Wi-Fi to utilities for smart grid networks to web services providers seeing the new commercial opportunities in this space…
- What is the business model of the future so that investments get made? The concern is that without a sustainable market for wireless network services we must rely on either a single national monopoly or alternative/cooperative networks, both of which have competition and QoS issues.
- A question was raised as to whether the modelling approach used in the study should cover applications other than those suited to wireless broadband.

### Section 3: Open discussion

The third session provided the main opportunity for stakeholders to respond to the study's findings:

- Alternative models of communications networks are being considered by players who are not the traditional incumbents (ie, MNOs, broadcasters and public services) and who welcome sharing – WSD, Wi-Fi, etc – and who are now testing novel schemes like TV over WSD etc.
- For an alternative network, backhaul is a problem. Sharing that with the mobile infrastructure would be a positive move, implying co-location.
- The view was expressed that it would take many years to get a cleared block of LE spectrum in the UHF band.
- Having many transmitters in close proximity produces major intermodulation problems, although digital processing can mitigate this.

- WiFi has been used in rural settings for fixed wireless access successfully for many years, and the huge improvements possible in Wi-Fi could make it do more.
- Civilian emergency services do not need enormous range at a disaster site and so agreement is being reached with the military for emergency services to gain shared use of a 50 MHz band at 4.9 GHz.
- A form of LTE for use in an LE band is being developed, for a mode of use comparable to Wi-Fi.
- Capacity should really be measured in bits per unit area, not in bits per MHz.
- The process of changing allocations and assignments can be very slow – 10 years to change an MSS allocation, for example. Inefficient old equipment remains in use for a long time (especially military), taking up valuable spectrum. One part of the solution is technology-neutral licences. Are technology based allocations the most efficient way to partition the spectrum?
- FM radio bands offer some possible scope for white spaces.
- Everyone wants to be at the low end of the spectrum, so this is the best region for sharing, especially as less power is required for good signal range.
- NRAs are not moving fast enough to enable the use of cognitive radio. This will hobble the development of the CR industry in Europe. Moreover the CR industry needs to concentrate on a single technology type and then produce competitive products.
- In some circumstances analogue modulation is more spectrally efficient than digital.
- The EC wishes to examine CR, MIMO and SDR more carefully next year as it is expected that manufacturers will soon put (more) intelligence into radio systems.
- Mixing shared access and LE access is possible now and is envisaged in ETSI standards work. Field tests are currently under way for CR based on SDR with MIMO, with self-organizing networks. In such cases, a geographical database is not needed. Only the first version of CR is under test. Real CR is yet to come.
- Current signalling protocols have a lot of overhead and this has yet to be overcome. It will take many years before a handset can detect spectrum dynamically. The starting point is managed use of CR for dynamic spectrum access (DSA) leading to more autonomous dynamic access with less infrastructural control.
- Greece opened the 60 GHz band for LE networks but nobody invested. Investors want the market protection of licences, rather than the light licensing proposed for 2012.
- A major area for progress in standards to enhance band sharing is on the receiver side: industry must invest in higher quality receivers in order to make sharing work.
- LTE is all there today.
- LTE has a lot more to roll out yet – it is not there today.
- For large-scale Wi-Fi rollout, where is investment coming from? An evolutionary path will be best.
- There needs to be more sharing among the public services on a common platform, with other related services such as the utilities. We should be constructing a shared wireless intranet for all these public bodies.
- Light licensing offers SMEs an affordable entry path to spectrum use in order to maximize the socio-economic benefits of sharing
- Licence-exempt is not easier for industry.

- There is a dichotomy here: the network operators that sell services and the suppliers that sell them equipment and handsets both want licensing, for guaranteed stability of position in the market.. Small players need to enter the market as cheaply and fast as possible and so they want Licence-Exempt (LE). Light licensing (LL) offers uncertainty to both. Realistically a primary licence holder may refuse to sublet frequencies to new small entrants because the primary gains nothing but more competition and sees his licence only as a source of income. End-users – the public – do not enter into this debate.
- The mobile industry is interested in more spectrum and use of CR and SDR but is less enthusiastic about light licensing (LL). In general the time to reallocate the spectrum needs to be shortened – the example of MSS at 2.1 GHz being unused for 10 years demonstrates the problem. The EC needs to accelerate the allocation process, especially for the 3.4-3.6 GHz band. The fact that this band is now used by WiMAX but identified for LTE (IMT), will make new deployments very slow.
- The Commission is trying to accelerate the process by working with all member states at the EU level. The problem is that this more than an EU level decision. A global agreement is necessary but that takes 5-10 years. Rapid allocation can occur – eg LTE at 900MHz – and the RSPG process is faster.
- Administrations must keep in mind that they will lose significant spectrum fees with Licence Exempt – of the order of 100Mn€ per year.
- There needs to be more shared spectrum and more than the 400MHz shown in Scenario 3 – that is not enough. But we also need to collaborate much more – and much better – in re-balancing use of the spectrum.
- Offloading via Wi-Fi poses questions of who pays - the MNO or the customer – or both. If MNOs take the data traffic (via Wi-Fi), how will their tariffs evolve?
- For all that will be carried over wireless broadband, there needs to be a harmonization of traffic levels, whether for internet surfing, TV, sound broadcasting or whatever.
- LTE licence auctions now being held all over Europe to distribute the Digital Dividend, will supply all the bandwidth anyone will need, so no additional Licence Exempt bands are necessary. By 2020, 90% of the EU population will have access to LTE - and at 30Mbps. Traditionally, licensed allocations will deliver everything. WiFi will be redundant, so shared access spectrum is not needed either.
- The utility companies have their own set of spectrum requirements, for traffic with very different characteristics than mobile telephony. Spectrum managers must consider far more than just the MNOs and broadcasters. What is unclear is why these types of operators should have precedence over other spectrum users. There are lots of small diverse applications that aggregate into large demands for spectrum. How will these demands be met if everything goes to these two services? It is unclear who would pay for the spectrum the niche players require. So licence exempt is an attractive solution. This problem needs leadership but the niche players are unorganized.