Spectrum Management in the Mobile Broadband Era

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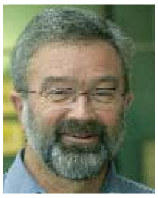

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When entering the second decade of the new millennium mobile communications experiences several shifts. Up to this date, mobile communications have been synonymous with mobile telephony. Not so anymore. Already now, the market appreciation of powerful data services combined with the ambition 'working or playing anywhere anytime' is conspicuous. This coincides with extending the IP protocol all the way to the mobile terminal, thereby putting mobile VoIP on the agenda. The demand for capacity both over the radio interface and backhaul network will be of quite another magnitude than before. The technology shift comes during the liberalisation of spectrum management, including free first-hand market, free second-hand market and technology neutrality. Demand for more spectrum will be imminent and so will demand for spectrum at different levels of the radio frequency spectrum, at least the opportunity to combine spectrum both below and above 1.5 GHz.

This article takes the reader through the major challenges emerging in this demanding landscape and suggests where the spectrum wells for mobile broadband will be found in the next decade.

1 Introduction

In a European perspective, spectrum management has gained a stronger attention and international momentum over the last two decades. One important feature of a successful handling of spectrum on an international level is the degree of harmonisation of spectrum usage. Multilateral negotiations on an EU level and in CEPT and ITU have contributed substantially to a shift in the direction of a more homogeneous market for efficient use of spectrum across national borders. Among the benefits of harmonised technical conditions for the use of spectrum are interoperability, easy cross border coordination and international roaming. Harmonised usage conditions also assist economies of scale to the vendor industry and increase the availability of affordable products.

Spectrum is becoming increasingly important to the mobile industry and is recognised as the most vital and valuable asset of a mobile operator. Spectrum is a scarce resource managed by the National Regulatory Authority (NRA) in a country and is recognised as a public good. Access to this natural resource is essential to all mobile communications operations. On an international level, only a few frequency bands are harmonised for the provisioning of mobile communications technologies. The frequency bands recognised as the commercially most important ones are the 900/1800/2100/2600 and 800 MHz bands. Spectrum which can be used to produce commercial services such as GSM and mobile broadband has a high economic value to the industry, but also a high socio-economic value to society and consumers.

In this picture, where competition adds to the technology development, the basic requirement of the spectrum management is: to allow for flexibility – eg. in terms of refarming – in a framework of consistent and stable rules. A spectrum management regime like that will assist the industry in deploying multiple technologies in the harmonised parts of the spectrum, and hence provide new services in a cost efficient way to the end user.

Today, we are facing a strong shift from fixed-line services to mobile services as consumers express a great demand for the availability of voice and data services independent on where they are located. The deployment of mobile broadband is uniquely positioned to compensate the lack of adequate fixed-line broadband infrastructure, in particular in rural areas. In acknowledging the consumer needs and demand for mobile services as part of their everyday life, access to spectrum harmonised for mobile technologies is considered as key to unleash the mobile broadband potential.

Despite the following text having a global scope, the focus will be on European spectrum management, and most of the examples will be from the Nordic countries.

2 Characteristics of the Frequency Bands in Lower and Upper Parts of the Radio Frequency Spectrum

The electromagnetic spectrum incorporates the full range of all electromagnetic radiation, and extends from electric power at the long-wavelength end to gamma radiation at the short-wavelength end. In between, we find radio waves, infra-red, visible light, ultra violet and X-rays used in medical diagnostics.

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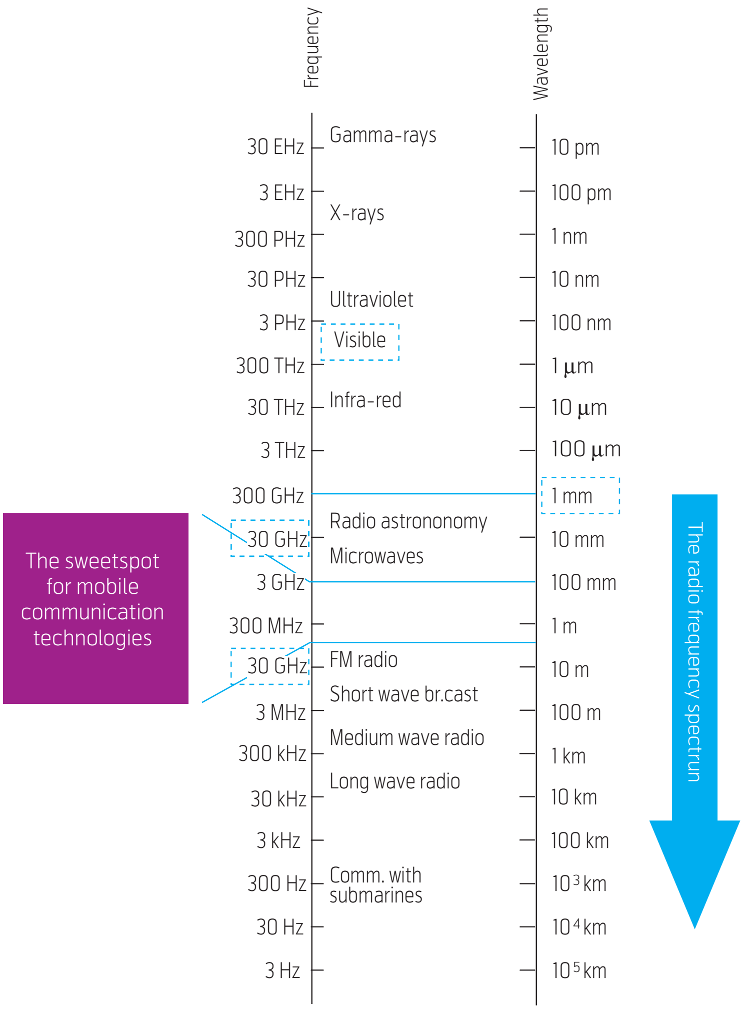

Figure 1 The electromagnetic spectrum and the sweetspot for mobile communication technologies

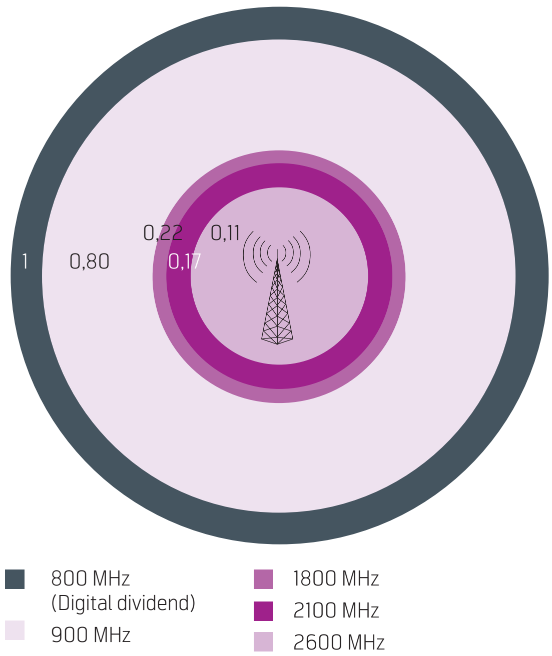

Figure 2 Relative cell size for different frequency bands, given same technical conditions

Some even claim that the spectrum is as big as the universe itself. In our context it is important to note that the radio frequency spectrum is only a relatively small part of the electromagnetic spectrum, covering the range from roughly 3 kHz to 300 GHz. This is where we find the radio waves, generated by transmitters and received by antennas or aerials. Within the radio frequency spectrum, the propagation characteristics vary, eg. in terms of ability to spread, penetrate, and curve around corners. The portion roughly between 200 MHz and 3 GHz is sometimes referred to as the 'sweetspot' (see [1]), and this is where most modern communication technologies such as DAB Digital Radio, digital television, wireless Internet access and not least mobile phones operate. So, when spectrum is referred to as a scarce or even limited resource, it is usually this sweetspot we are referring to. Figure 1 illustrates the full range of the electromagnetic spectrum, the radio frequency spectrum and the position of the sweetspot in this range.

Even within the sweetspot, the propagation characteristics differ, as signals in the lower part of this spectrum travel longer distances, penetrate materials better and curve more easily around corners. Therefore, these lower parts are especially attractive to mobile communications due to the ability to provide continuous coverage with fewer base stations (less densely located) within a given geographical area. On the other hand, there is inevitably more spectral elbowroom in the higher parts of the spectrum (at the cost of coverage efficiency). Therefore, the upper bands are often referred to as the *capacity bands,* whereas the lower bands are often referred to as the *coverage bands*.

As a rule of thumb, we may state that frequencies below 1 GHz are considered as coverage bands, whereas the frequencies between 1 and 3 GHz are considered as capacity bands. Coverage bands provide for a more cost efficient build-out in suburban/ rural areas. Capacity bands, on the other hand, are mainly used in urban/high density areas with high traffic volume requirements. Figure 2 illustrates the relative theoretical cell size for the most relevant mobile communication bands, given equal conditions, including the same technology. This also then indicates the relative number of base stations required to cover a certain geographical area.

The combination of less available bandwidth, capacity and good coverage characteristics make spectrum in the coverage bands attractive and in high demand in the spectrum marketplace. This is also usually directly reflected in the price per MHz per population reached in spectrum auctions.

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3 A Major Paradigm Shift in Spectrum Management: From Command-and-Control to a Liberal Regime

Management of spectrum used for offering wireless services to consumers was introduced in the broadcasting domain in the western world between World War I and World War II. To put an end to the increasing radio transmission anarchy of the rapidly growing radio broadcast business, it was decided that a broadcasting company had to receive permission or a license before entering business. The license would comprise information about the frequency band in which the company was allowed to broadcast its programs. Gradually, radio spectrum was being used to offer also other services than radio programs on a broadcast basis, but the basis of spectrum management prevailed: in most cases the provider of the wireless services had to apply for a license. The license that the provider then might obtain would contain all necessary information concerning the frequency band to be used; the maximum output power that was allowed, the applicable geographical area etc. This type of regime for spectrum assignment is often referred to as 'command-and-control'.

Command-and-control management continued until the introduction of competition became an issue. This was a period of monopoly, and the provider of wireless services and the spectrum manager were most often parts of the same organisation.

In the late 1980s and early 1990s competition was introduced in mobile communications within Europe. In some cases, eg. in Norway in 1991 when launching GSM services, this was achieved by opening up for a parallel license to one of the licenses of the monopolist. Competition was considered to have been established when the incumbent was faced with a competitor. However, by the next license award of spectrum in the 1800 MHz band in 1998, it was opened up for more than two licensees, and the previous monopolist Telenor had to apply, as well as any other party.

In this period the challenge of choosing between a number of applicants being bigger than the number of licenses introduced a selection process that has often been called 'beauty contest'. The constraints normally attached to such a process were –

- The technology to be applied;
- The service to be offered;
- The frequency blocks subject to application;
- Technical constraints like maximum output power etc.;
- Minimum coverage requirements.

The regulatory authorities were then to choose among the applicants on the basis of a set of criteria that were normally quite blurred. The applications most often concentrated on the ambitions of the individual applicant, the estimated number of new jobs created by the business initiative, commitment to provision of service coverage or quality etc.

As competition increased and technology became gradually more complex, the requirements to spectrum management changed. It became ever more difficult to administrate spectrum according to the past regime. It became ever more difficult to pick services and technologies for the different frequency bands that would make an optimal fit for the decade to come in terms of public demands. It proved to be very difficult to verify the promises made by new licensees in terms of service quality and coverage. But most important: monopolies vaporised to give room for the process towards a totally liberalised industry of providing telecom services. The demand of fair and transparent processes for granting any type of assets vital to wireless business proved to be almost incompatible with command-and-control.

Thus, in Europe a regime of fully liberalised spectrum management was gradually emerging, first of all promoted and headed by the UK NRA Ofcom. The liberal forerunners advocated the position that the only way to meet the challenge of the modern world was to establish a regime of free trade of spectrum – eg. just as the WTO defined rules for global trade of any goods or services. Three corner stones of such a regime for spectrum management were established: i) free first-hand market, ii) free second-hand market, and iii) technology neutrality.

3.1 Free First-Hand Market

The spectrum management regime in Norway has fully adopted this view, and may be regarded to be at approximately the same level of liberal management as Ofcom. Virgin frequency bands that may be anticipated to be of common interest in the market and that are not previously allocated for a certain service or technology, will be subject to auctions on a technology neutral basis; this happened to the 3.5 GHz band in 2004 and the 2.6 GHz band in 2007. Frequency resources that are vacant, eg. after an auction, remain vacant until some player files an application for them. The occurrence of an application is then made public, and the frequency resources go to the applicant if there is no further demand for them, otherwise there will be an auction. The same liberal approach applies to a license that is expiring. Instead of prolonging the validity period of the license or making it subject to automatic 'renewal' to the benefit of the current licensee, the license will be subject to a possible

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're-buying' in a process quite similar to the one of acquiring idle spectrum: the new license goes to the current licensee if he is willing to pay the minimum price determined by the NRA, but if there are other players interested in that frequency band, there will be an auction. This was the procedure that was followed in Norway when Telenor and NetCom obtained new licenses in the 900 MHz band to replace the ones that had expired.

3.2 Free Second-Hand Market

Spectrum trading is allowed in ever wider parts of the radio spectrum in Norway, and that opportunity was first taken by mobile operators in the early 2000s, when a license purchased in the auction in 2001 on the 900 MHz band by BaneTele was later transferred to Harald A Moeller (Moeller Group), who passed it on to Network Norway. The regulator was to be notified and to approve of those transfers, but in those cases that appeared to be more or less formalism. A side effect of the ambition free spectrum trading is that regulators tend to gradually discard the habit of including requirements on roll-out and coverage in the licenses to be issued. Such obligations do not go well together with a fluent and well-functioning second hand market.

3.3 Technology Neutrality

Technology neutrality is a clear ambition in spectrum management in Norway, and virgin frequency bands to be exploited are declared technology neutral, eg. the 3.5 GHz and the 2.6 GHz bands that were subject to auctions in 2004 and 2007, respectively.

When it comes to frequency bands that are already used, the procedure is not that simple. The procedures for a so-called 'refarming' of the 900 and 1800 MHz bands have caused headache to many a European regulator; see more on this in Section 5.8.

The considerations in this chapter all relate to business based upon licenses with exclusive rights to specified spectrum resources. Since spectrum is a scarce resource discussions are almost permanently going on around principles for spectrum management. Thus, there is a lobby with significant influence in Europe advocating for an increased amount of radio spectrum on a license exempt basis at the expense of the amount of spectrum subject to exclusive rights licensing. It is not expected that this will impact the management principles of the 'mobile frequency bands' within the next 10 to 15 years.

4 Mobile Broadband – the Future Band Wagon of Mobile Communications

The main focus when defining the first two generations of mobile communications was without doubt the provision of voice telephony – although some of the first generation (1G) systems, such as NMT, TACS and AMPS, did contain very limited data capabilities. The second generation (2G) system GSM did include a basic circuit switched data service capability, and of course the text messaging service SMS is by nature a data service although extremely bandwidth limited. It is also interesting to note that one of the main predecessors to mobile communications as we know it today – the pager – was indeed a data service, but its main purpose was to notify for and subsequently generate a voice call.

The lack of adequate data capabilities did not seem to worry most users, as general demand for data services (even in the fixed networks) in the early eighties was limited. However, once deployment and popularity of the Internet gained speed, this picture was about to change radically. It soon became clear that the circuit switched data capabilities of GSM proved insufficient even for basic internet browsing and e-mail. Further improvements through 2.5G capabilities such as EDGE and GPRS were important steps, but the gap between these mobile data services and the evolving fixed line services was too large, and mobile was still not regarded as a serious alternative for data communications. The introduction of WAP generated quite a hype initially, but it was probably most important as an indicator for what to expect some years later and subsequently with the introduction of 3G/UMTS a sound basis for more powerful mobile data capabilities was established.

The main breakthrough however came with the introduction of HSDPA, also denoted 3.5G. This was launched by Telenor in 2007 and it was this service that took on the label Mobile Broadband for the first time and marked the beginning of the mobile broadband era. Since this service launch, the mobile data volume in the Telenor network has shown an enormous growth and this trend continues. Even now with a broader diversity of users on board and not only the 'first movers', the traffic generated per user continues to increase with the main volumes generated from laptop PCs. In addition, data via small screen terminals is picking up fuelled by innovative handsets such as the iPhone. Mobile data started up as an add-on to the voice telephony service. Soon mobile broadband will be considered equally important as voice on any mobile communications device.

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These developments imply that it is no longer voice telephony but rather mobile broadband which is the dominating factor when it comes to the dimensioning and planning of the radio access networks, the core network, the backbone and not least the spectrum resources. Moving from 2 x 200 kHz channel bandwidth for 2G voice via 2 x 5 MHz for 3G/3.5G to up to 2 x 20 MHz for LTE definitely changes the rules and the need for more spectrum, re-farming and technology neutrality are all driven by this evolution, an evolution which is only at its early stage.

5 Frequency Bands Suitable for Mobile Broadband Services

5.1 The 450 MHz Band – the Starting Point for Several 1G Networks

When the first automatic mobile telephone systems – 1G – were specified and implemented in the 1980s, the 450 MHz band (see Table 3) was chosen as the target frequency band in many countries inside and outside Europe. The NMT system, which became a success also outside the Nordic countries, was in Norway running in the frequency band 453.0 – 457.5 MHz (uplink) and 463 – 467.5 MHz (downlink). The frequency bands for most 1G technologies were narrow (2 x ~5 MHz), but as they all resided in the lower end of the UHF band they provided 1G systems with a very good coverage economy.

At the end of the 1990s some vendors took an initiative to establish specifications for GSM in the 450 MHz band. Operators – eg. Telenor – were asked if they would consider establishing a 2G operation in the 450 MHz band. Since NMT 450 networks were still in operation in most places at that time, the responses from most operators to the vendors were negative and production lines for GSM in the 450 MHz band were never established. One might assume that the operators today regret their answers.

After expiry of the 1G licenses in Europe, mobile data (only) systems based on the CDMA family appeared to be the only ones that could replace the analogue technology in the 450 MHz band. Thus, CDMA450 was then introduced in many former ‘NMT countries’, among them Norway.

5.2 The 900 MHz Band – the Cradle of Digital Mobile Communications

The first chairman of the work in CEPT and later ETSI on making specifications for GSM – Thomas Haug – once commented on the reasons behind the GSM initiative in the early 1980s. He emphasized that the purpose was neither industry policy (even if GSM became one of the most successful industry collaborations in Europe ever) nor some sort of window of opportunity in terms of technology, eg. to establish a system for digital mobile communications in Europe. As he put it, it was “the last chance to find a common frequency band that would enable Europe to have a pan-European mobile communications system before the end of the century”. The opportunity was represented by the upper 2 x 25 MHz of the 900 MHz band (see Table 3), the so-called P-GSM band (or Primary-GSM band). Later the 2 x 10 MHz below the P-GSM band was added to the band harmonised for GSM, the so-called E-GSM band (or Extended-GSM band)[1]. Harmonisation of this early part of the 900 MHz band – both in terms of freeing it for other current or planned applications and making GSM the mandatory application in that frequency band by the so-called ‘GSM directive’[2] – together with the Memorandum of Understanding[3] made the GSM technology a tremendous success, in contrast to so many other standards produced by bodies like CEPT and ETSI.

A basic prerequisite for success in the mobile business is to make the industry interested in and eager to invest in certain network technologies and services in a specific frequency band. It follows from this that once such an attraction has been aroused and a substantial amount of equipment has been deployed, this frequency band will also be target for the heirs of the original technology, if such genealogy exists. Since 3GPP has been wise to prepare for and specify a well defined road map 2G –> 3G –> 4G, the so-called ‘GSM bands’ will probably to a great extent be tied to that family of technologies, despite the paradigm of technology neutrality. This applies in particular to the 900 MHz band, since it was the first band to be a spectrum basis for the provision of GSM services.

It was not possible to make the 900 MHz band subject to a global harmonisation. In some parts of the world, this frequency band could not be cleaned and

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1) *Note that the term ‘E-GSM band’ may appear to have some ambiguous interpretation. Sometimes it refers to the additional 2 x 10 MHz added to the P-GSM band; sometimes it refers to the current 2 x 35 MHz of the 900 MHz band.*

2) *The ‘GSM Directive’ (Council Directive 87/372/EEC of 25 June 1987) addressed the frequency bands to be reserved for the coordinated introduction of public pan-European cellular digital land-based mobile communications in the European Community. Even if the term ‘GSM’ was not used in the directive, it got its name since it was obvious that it addressed the use of GSM in the 900 MHz band and – eventually – in the 1800 MHz band.*

3) *The Memorandum of Understanding was a document signed by all major mobile operators in Europe declaring their sincere intent to deploy the GSM system.*

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made ready for GSM. However, in most of those cases some nearby frequency band could after some tidying up serve as a GSM band.

5.3 The 1800 MHz Band – the Second Band Opened for 2G Communication

As it became apparent that mobile communications was a formidable success, the demand for more spectrum was correspondingly importunate. The next frequency band that seemed to be a suitable candidate for carrying GSM services was the 1800 MHz band (see Table 3). Also the 1800 MHz band was included in the GSM directive, thus becoming a pan-European frequency band for GSM use solely. European regulators all issued technology specific licenses firmly tying it to GSM technology.

The 1800 MHz band was however a frequency band with quite different characteristics in terms of propagation than the 900 MHz band. The consequences thereof soon became apparent. Originally, the 1800 MHz band was included in the pool of spectrum resources for GSM to increase competition among GSM operators. In the first years after the 1800 MHz band was opened for GSM operations, GSM 1800 operators competed with GSM 900 operators on equal terms. Gradually it became evident that this was an unfair playing scene. Particularly in countries where coverage normally was a significant competition parameter – eg. the Nordic countries – the GSM 1800 technology had a major disadvantage compared to GSM 900.

Operators that managed to acquire spectrum in both the 900 and the 1800 MHz bands appeared to have a better basis for business when applying the so-called 'dual band technology' being standardised in the mid 1990s, ie. a technology that allowed a GSM core network to be connected to BTS's featuring both GSM 900 and GSM 1800 frequencies. A GSM customer of such an operator might in a seamless way be subject to handover between the 900 MHz band and the 1800 MHz band. The advantage of dual band networks compared to 'single band networks' was compelling: dual band networks combined coverage economy (in the 900 MHz band part) with abundant capacity (in the 1800 MHz band part), whereas single band networks possessed only one of the components. The dual band operators that emerged in the very last years of the 1990s illustrated what will probably prove to be a prerequisite for any viable business endeavour in mobile communications of the future: it has to rely on frequencies in the lower part of the spectrum as well as in the upper part of the spectrum.

Dual band technology conquered the market from the last half of the 1990s and onwards. In Norway Telenor and NetCom received their 1800 MHz band licenses in 1998, and rolled out their 1800 networks based upon dual band technology. Dual band terminals appeared ever more frequently in the period 1998 – 2000.

As for the 900 MHz band, the 1800 MHz band could not be subject to worldwide harmonisation. In certain countries – eg. the US – spectrum managers had to find another frequency band who might carry GSM. Thus, two GSM technologies appeared in that part of the radio spectrum: GSM for the 1800 MHz band, the so-called DCS-1800, and GSM for the 1900 MHz band, the so-called PCS-1900.

5.4 The 2.1 GHz Band – the First Band Intended for 3G Communications

In the mid-1990s WARC decided upon a frequency band for technologies that were to succeed 2G. After lengthy discussions they came up with the band depicted in Figure 3, which has been the basis for later UMTS licenses. There were also lengthy discussions, however in other bodies, about whether licensing should be technology neutral or technology specific. The US did not approve of the technology specific way of licensing spectrum for future technologies that the EU intended to apply for Europe. A compromise emerged by which one created the concept '3rd Generation Mobile Communications', or '3G'. 3G consisted of the following set of technologies:

- CDMA2000
- WCDMA (UMTS)
- TD-CDMA (UMTS)
- TD-SCDMA (UMTS)
- DECT

A basic element of the compromise was that each of the European regulators should invite operators who would apply any of the five technologies mentioned above, but to enable international roaming the regulator had to make sure that there would be at least one UMTS operator in every country.

The 2.1 GHz band was subject to a series of awards from spring 2000. When considering the frequency band with hindsight we may confirm that despite the technology neutrality of the awards, it has truly become a 'UMTS band', or more precisely; a 'WCDMA band'.

The bid levels in the auctions of 3G that were held in the summer of 2000 went sky-high. As an illustration the winning bids in UK were:

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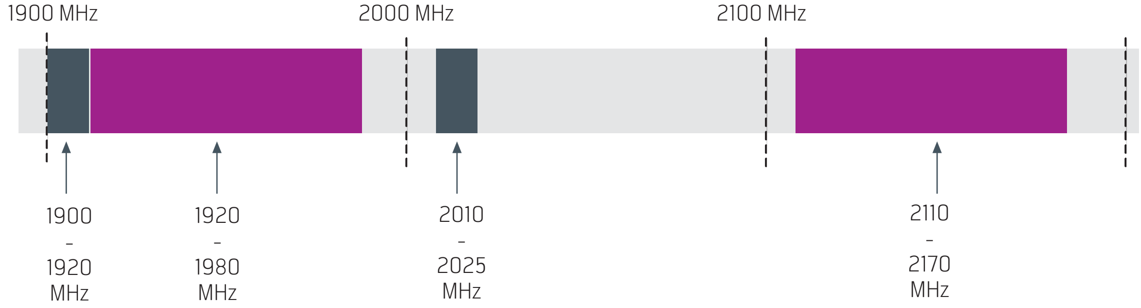

Figure 3 Spectrum reserved for 3G by global spectrum management bodies in the 1990s indicated by the coloured rectangles. The purple rectangles are those that emerged as candidates for FDD, leaving the dark grey rectangles as candidates for TDD

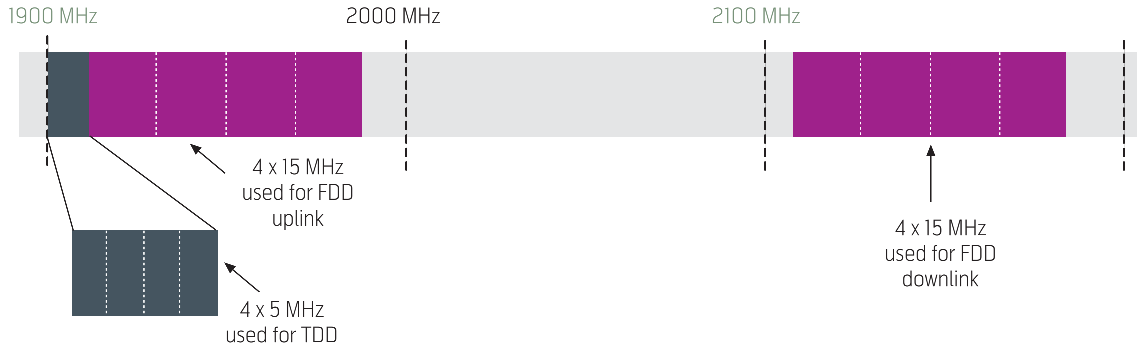

Figure 4 The most used scheme of exploiting the 3G spectrum, originally suggested by UMTS Forum: four licenses, each one comprising 2 x 15 MHz FDD + 5 MHz TDD

- TIW: £4,384.7 million
- Vodafone: £5,964.0 million
- BT3G: £4,030.1 million
- One2One: £4,003.6 million
- Orange: £4,095.0 million

These auctions still represent non-settled disputes in the different communities within mobile communications industry; were they examples of a sensible way to award spectrum, or not?

In Europe and several other regions in the world, the flavour of technology neutrality that had been added to the licensing of the 2.1 GHz band seemed to be superfluous; in almost every country in which UMTS was a realistic candidate, WCDMA was chosen by all licensees. But how should regulators balance competition versus bandwidth of frequency resources awarded to each licensee? To support the regulator community in this task and to possibly achieve a more coherent approach of implementing UMTS worldwide, UMTS Forum advised through a set of reports published in the last 1990s proposals for markets of different sizes. One of the preferences of UMTS Forum – four licenses, each of 2 x 15 MHz FDD + 5 MHz TDD – became also the most used, eg. by regulators in the Nordic countries, see also Figure 4.

5.5 The 3.5 GHz Band – the 'WiMAX Band'

When spectrum management bodies started to look at radio spectrum above 3 GHz in the late 1990s and early 2000s, several virgin frequency bands of considerable width seemed to be suitable for point-to-point communication. One of those was the 3.5 GHz band, for which global and regional planning was finalised at approximately the same time as the technologies within the WiMAX family were defined. The first ones of those technologies, eg. IEEE 802.16d, were intended for fixed links or nomadic computing primarily, since its channel coding did not make it suitable for communication with mobile terminals at speeds way above walking pace.

Still, WiMAX in the 3.5 GHz band was a hot issue in 2003 – 2005 when the first licenses were given, and therefore the 3.5 GHz band has been commonly known as 'the WiMAX band'. This will perhaps turn out to be at the expense of true technology neutrality of this band, as vendors of equipment in other technologies for quite some period of time may be reluctant to include the 3.5 GHz band in their product line. On the other hand, the frequency band 3.4 – 3.8 GHz is by many experts regarded as one of the major bands for current and future broadband needs, since it represents one of the very few options for provision

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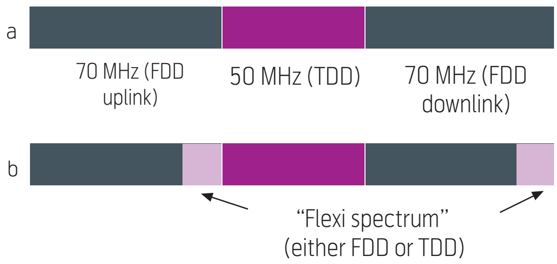

Figure 5 Channel band plan for the 2.6 GHz band. Alternative a) is recommended by eg. CEPT for Europe. However, some regulators deviated slightly from this scheme. Alternative b) indicates the approach of the Norwegian regulator: it is similar to the CEPT approach apart from the 'flexi spectrum', ie. 2 x 30 MHz that may be utilised either as FDD or as TDD[3)]

of several licenses for future bandwidth-demanding technologies, such as LTE-A.

5.6 The 2.6 GHz Band – the 'Extension Band'

The perspectives in the early 2000s in terms of UMTS potential and life time were very optimistic. At the WARCs during this period one therefore spent considerable time and effort on the harmonisation of another frequency band for UMTS services in addition to the 2.1 GHz band. The frequency band that seemed most suitable – since it was the easiest to harmonize – was the 2.6 GHz band.

A considerable part of the discussions on preparation for the allocation of the 2.6 GHz band was to define a channel plan to locate the FDD and TDD parts. Gradually, most spectrum management bodies ended up with a solution close to the plan: 70 MHz uplink FDD – 50 MHz TDD – 70 MHz downlink FDD, see Figure 5.

The notation 'extension band', which in the beginning was used quite frequently when referring to the 2.6 GHz band, pointed at the contemporary concern of not having enough spectrum for the future demand of 3G. Before the 2.1 GHz band was fully exploited, 4G technology has appeared on the stage. Since most regulators in Europe probably will allow for licensing procedures that open up for technology neutrality to encompass both UMTS and LTE, those are technologies that both may appear in this band. Today, the term 'extension band' is therefore more or less obsolete. LTE seems by far to be the primary choice of operators that just have obtained a license in the 2.6 GHz band.

5.7 The 800 MHz Band – the Digital Dividend

During the last two decades a major dispute has been going on between the two communities of broadcast and wireless communication. This was due to the approaching conversion from analogue to digital technology in the broadcast business. As transmission of digital TV signals requires less bandwidth than analogue transmission, the community of wireless communication argues that the conversion will free up a substantial amount of spectrum, the so-called 'digital dividend' (see Table 3).

The broadcast community however argued that during the past two or three decades the demand for more TV channels and more bandwidth consuming technologies had increased, so that there is in fact no dividend. The resulting compromise was that the 72 MHz upper part of the frequency band previously allocated to broadcast was to be defined as the digital dividend, and thus to be used possibly for other purposes than providing broadcast services. This was far less than eg. mobile operators originally had hoped for, but the compromise was finally endorsed by all parties and is expected to represent a guideline for spectrum management in a huge number of countries, including the Nordic ones.

In 2009 the European communities of spectrum management advised the regulators in Europe to adopt the following plan for the digital dividend, see Figure 6.

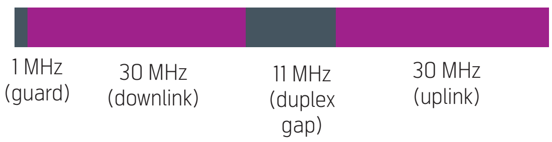

Figure 6 Channel plan for the 790-862 MHz band advised by CEPT to be followed by regulators in Europe

CEPT decided to advocate 1 MHz reserved as guard band between the dividend and the broadcasters in the lower parts of the spectrum, and to use 11 MHz for duplex separation. Furthermore, still due to the risk of imposing harmful interference towards the broadcasters beneath, downlink and uplink were swapped compared to what is common in most other FDD technologies.

3) *The reason behind the 'Norwegian approach' was that market demand should as far as possible be reflected in the actual use of spectrum. Since regional bodies for spectrum management were hardly expected to predict the market demand of FDD and TDD at such an early stage, it would be wise to let the bidders of the auction decide the relation between the FDD and the TDD spectrum of the 2.6 GHz band. When the auction in Norway was over, it appeared however that FDD and TDD operators had acquired spectrum more or less in accordance with the CEPT band plan, ie. most of the 'flexi spectrum' would be used according to FDD.*

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Despite the creed of technology neutrality that long ago has entered the European bodies of spectrum management, mobile broadband on the basis of LTE has been assessed to be the most likely application of the digital dividend during the considerations mentioned, and that has obviously had significant impact on the band plan considerations. The assessment of mobile broadband/LTE to be the major technology in the dividend seems to be shared by the wireless equipment industry.

In the autumn of 2009, EU made public a directive that urged broadcasters to speed up the process of the analogue TV switch off, emphasizing that this process should be completed by the end of 2012. The first awards of spectrum within the digital dividend are expected to take place during the course of 2010.

5.8 'Refarming' – Opening up for Technology Neutrality

In Chapter 3 the liberalisation of spectrum management was depicted. A major challenge in this process is to find practical ways to implement technology neutrality. This became imminent when the demand for introducing new technology – eg. UMTS – in the GSM bands appeared from 2005 and onwards.

To formally update the EU directives is one thing. Far more challenging seems to be to transform the existing technology specific licenses in those bands into technology neutral licenses without

- waiting for the expiry dates;
- distorting competition; and
- violating national or regional legislation.

An essential aspect of this challenge is of course the fact that spectrum managers of the early 1990s did not have in mind that the future building blocks would be 2 x 5 MHz. In Norway the situation in the 900 MHz band was however fairly simple, due to two facts: i) The frequency resources allocated to Mobile Norway (Network Norway), NetCom and Telenor happened to be close to 2 x 5 MHz, 2 x 15 MHz and 2 x 15 MHz, respectively. By adding to those licenses the so-called CT1-frequencies at the expiry of that allocation, the three operators got spectrum sufficient for implementing 2 x 5 MHz according to the above distribution. ii) There was no network operator active in the 2.1 GHz band that did not also have a license in the 900 MHz band. Hi3G – '3G' – possessed license only in the 2.1 GHz band, but has not so far taken any action to establish a network or start business in Norway[4]. Thus in this country, the regulatory gates to refarming may soon be opened; technology neutral licenses are expected to be issued spring 2010.

Corresponding to the efforts made to open up the 'GSM bands' – the 900 and the 1800 MHz bands – for other technologies than they were originally meant for, CEPT has been given the mandate to envisage procedures for how to make the 2.1 GHz band technology neutral. This means in practice that this band in the longer term may become a candidate for LTE operation.

5.9 The Spectrum Situation for Mobile Broadband

When considering the events of opening new frequency bands for mobile communications during the past two or three decades three aspects are apparent:

1) New technology has most commonly been introduced by just those events.

2) The technology stamp that the frequency band thus gets after the opening remains for a long time, even after the band has been 'refarmed' and made technology neutral. This is due to the 'technology inertia' mentioned earlier.

3) Barriers for the introduction of new technology as indicated in 1) and 2) may be overcome if some of the existing technology has a well defined scheme

Frequency band	Likely to be a carrier for mobile broadband	
	LTE family	WCDMA family
450 MHz band	sporadically used	extensively used
800 MHz band (Dig. Div.)	extensively used	infrequently used
900 MHz band	sporadically used	extensively used
1800 MHz band	sporadically used	infrequently used
2.1 GHz band	not used	extensively used
2.6 GHz band	extensively used	infrequently used
3.5 GHz band	not used	not used

Table 1 The assessment of probability for each of the 'mobile frequency bands' in Europe to carry mobile broadband during the next six years:

extensively used (grey) · *infrequently used* (yellow) · *sporadically used* (tan) · *not used* (purple)

[4] *In eg. Sweden, where Hi3G did make considerable investments, they took part in the dispute on management of the 900 MHz band in connection with the Swedish process of refarming this band.*

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for technology successors that reach to the level of state-of-the-art.

When looking for inlets of mobile broadband in the radio spectrum one should bear in mind the three aspects depicted above. Of course, the positioning of the wireless and mobile industry is also of extreme importance, but that is often a result of a careful analysis of the very same three aspects.

Doing so, one might establish an assessment as indicated in Table 1.

6 Aspects of Importance to the Mobile Broadband Business

Economy of scale in the mobile broadband business is dependent on harmonisation of spectrum and standardised equipment. National regulatory bodies should ensure that spectrum harmonised for mobile communications technologies, such as mobile broadband, is released and assigned in a timely manner in order to let the society enjoy the benefits of getting access to broadband and Internet even in rural areas.

In rural areas the use of coverage bands (ref. section 2) can contribute to significant advantages when it comes to rolling out mobile broadband in a fast and cost-efficient way. Spectrum in the 800 and 900 MHz bands has excellent propagation and coverage characteristics which are important for an efficient deployment of mobile broadband, in particular in rural areas. Compared to spectrum in the 1800 MHz and 2100 MHz band, fewer base stations are required to deploy 3G/4G in the 800 and 900 MHz. The need for fewer base stations means a faster roll-out of the network and dramatically reduced cost for the operators.

Access to right spectrum and a predictable and consistent regulatory regime will have a significant impact on the quality and quantity of services provided to consumers.

Fixed-line access service faces a number of barriers which are likely to prevent significant new build-outs in developing countries, especially in areas where the required bandwidth is relatively low. For instance, many emerging markets have poor existing copper infrastructure to begin with, with an inherently inefficient structure (long loops, multiple joints). Frequently, the infrastructure faces deterioration due to copper theft. Additional roll-out can be cumbersome and expensive – not only does it require physical digging and the resolution of right-of-way issues; in lower-density areas it also needs a large field force for maintenance. On the demand side, unreliable electricity services can limit personal computer usage, thus reducing the consumer's ability to access fixed-line broadband.

Mobile networks, on the other hand, are forecast to achieve significant penetration levels in developing/emerging economies in the relatively near future. By 2012, Central and Eastern Europe should achieve a penetration rate of 130 percent, Latin America should exceed 90 percent and Asia and Africa/Middle East should both reach nearly 65 percent, see also [2].

Telecom has an impact on economic growth and regulatory predictability reduces uncertainty and encourages investments and innovation. To minimize uncertainty, governments and regulators should ensure that the regulatory framework, including the spectrum management policy, is sound and reliable. Flexibility in managing the use of spectrum rights should be granted to operators in order to give them the necessary room for maneuver to operate within the license framework. Thus, licenses should contain only a minimum of conditions.

7 The Current Situation in Different Areas of the World

7.1 Europe

The degree of penetration of mobile communications technology and services is dependent on spectrum availability. Over the last ten years, many countries have assigned spectrum in the 2.1 GHz band for UMTS services, and many countries in Europe have or are currently in the process of assigning the 2.6 GHz band. Furthermore, opening up the 900 and 1800 MHz band for UMTS and subsequently LTE services is also one of the trends in the spectrum management landscape of Europe. Use of spectrum in the coverage bands can drastically reduce the capital expenditures operators have to make for base stations, especially in rural areas, due to the greater coverage that lower spectrum provides.

In US the 700 MHz spectrum (UHF band) was made available in 2008. Several European countries are in the process of preparing the ground for auctions and assignment of the 800 MHz band for mobile communications services, and it is likely that licenses in this band will be auctioned already in 2010 according to government announcements.

According to a report from the European Commission published 18 November 2009 [3], the penetration of mobile broadband in EU27 as measured by dedicated data service cards/modems/keys was 4.2% in July 2009 (up from 2.8% in January 2009).

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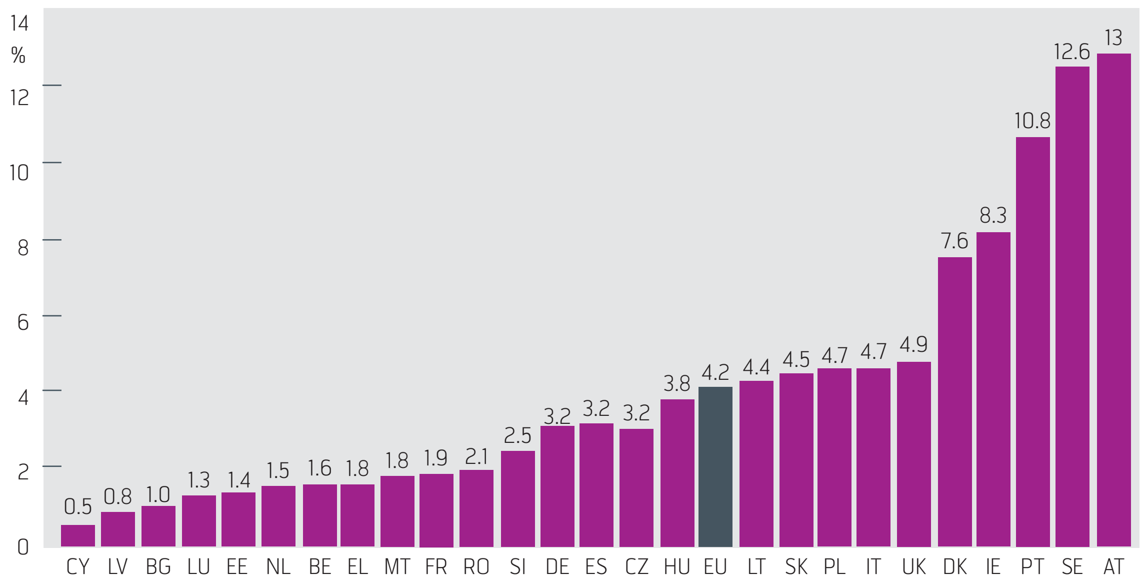

Figure 7 EU countries by number of mobile broadband users (dedicated data services cards/modems/keys) per 100 population

In its press release of the report, the European Commission stated that, "Despite the economic slowdown, Europe continues to have a very dynamic broadband market. Enhanced competition is driving better services, and consumers nowadays regard their broadband internet access as an essential part of life."

According to the Commission Report, Denmark and the Netherlands continue to be world leaders in broadband take up, with nearly 40% of the population having a fixed broadband connection, but growth rates are slowing as they approach saturation. Nine EU countries (Denmark 37.3%, the Netherlands 36.2%, Sweden 31.3%, Finland 30.7%, Luxembourg 28.8%, the United Kingdom 28.4%, France 27.7%, Germany 27.5% and now also Belgium 27.5%) are above the United States, where the level of broadband take up stands at 25.8% and is slowing according to OECD May 2009 statistics. Luxembourg (+18.3%) and Portugal (+11.7%) experienced faster growth in 2009 than in 2008.

EU countries by number of mobile broadband users (dedicated data services cards/modems/keys) per 100 population is shown in Figure 7.

7.2 Outside of Europe

Mobile technologies are the primary source of communications for much of the population in the Asian region of the world. In lack of sound infrastructure for fixed broadband, in particular in rural areas in several Asian countries, mobile broadband is expected to be significant to make Internet accessible for the population living outside urban areas. To enable mobile operators to make mobile broadband available in a country, access to spectrum on conditions that allow for innovation and further investments are crucial to the industry to supply affordable mobile communications services to consumers. In order to be able to do this, the mobile industry needs clear and coherent regulatory conditions such as allocation of internationally harmonised frequency bands and implementation of internationally harmonised band plans. Operators are not only dependent on harmonised spectrum, but also standardised equipment that has implemented support for eg. 3G technology using harmonised spectrum. Mobile operators and vendors are mutually dependent on each other to act in a coordinated way to provide the best possible services at lowest cost possible to consumers in emerging markets.

The environment for licensing and spectrum management across Asia Pacific varies along the lines of emerging and developed economies. In markets recognised as developed, eg. Australia (Telstra started to roll-out WCDMA in the 850 MHz band in 2005) and New Zealand, 3G spectrum licenses have been available in the market for several years. In emerging markets, where governments have announced that 3G licenses are planned to be issued (eg. India and Thailand), the way spectrum will be allocated and assigned will have an impact on how many people will actually get access to technologies and services such as mobile broadband.

From an operator point of view, the industry is facing several challenges when it comes to spectrum management including allocation and assignment of this scarce resource. To provide high-quality broadband

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access and services to consumers, the industry is dependent on:

- Access to harmonised spectrum for mobile communications such as 850, 900, 1800, 2100, 2600 and 700/800 MHz spectrum;
- Access to the right amount of spectrum on conditions that provide for sustainable competition in the market for electronic mobile communications;
- Efficient, objective, proportionate and non-discriminatory spectrum allocation and assignment processes.

Among the markets in Asia where Telenor operates (Malaysia, Thailand, Bangladesh, Pakistan and India), only Malaysia has issued 3G licenses in the 2100 MHz band. However, the governments in Thailand, Bangladesh, Pakistan and India have scheduled that this band will be allocated and licenses to be assigned in the next years to come.

A few countries in the Asia Pacific region have allowed operators to deploy 3G in the 900 MHz band (eg. Thailand and Australia). For operators in Asia, it would be a great advantage if the national licensing regimes would allow the operators to optimise the use of spectrum licenses, eg. optimise between GSM and UMTS in the 900 and 1800 MHz band. Allowing operators to choose which technology to deploy in a band, within the technical limits in order not to cause in-band interference or interference into neighbouring bands and technologies, leaves much more flexibility to operators to manage their spectrum usage more efficiently. If infrastructure supporting GSM in the 900 MHz band has already been rolled out, deploying UMTS in the same band will allow the operators to roll out and provide 3G services to consumers in a more cost-efficient and faster way than for instance building a new network in the 2100 MHz band.

In allowing the operators to use spectrum more efficiently and in a flexible manner, there is a strong need to ensure a level playing field for all market participants during the transition process of deploying 3G in bands originally reserved for 2G technologies and services. This is considered as a key priority to realise the maximum benefits from investment in infrastructure for mobile broadband.

As in Europe, the process of releasing the UHF band for mobile communications services is under way also in Asia. However, with regard to timing, the development of a bandplan for the Asia Pacific region is lagging behind the development in Europe. The part of the UHF band recognised for mobile services in the Asia Pacific region is 790 – 862 MHz in some countries, and 698 – 806 MHz in other countries. Currently, an on-going discussion in the region is taking place among operators, vendors and industry organisations with a focus to develop a band plan for the upper part of the UHF-band (698 – 806 MHz). The mobile industry and the vendors have proposed that all countries in the Asia Pacific region should consider the use of the UHF band for mobile services, in order to benefit from the significant advantages of using the UHF band to provide ubiquitous, affordable mobile broadband services. To reap the full benefits of the UHF band in the Asia Pacific region, it is important that there exists a common alignment regionally to realise the potential economies of scale, and thereby prepare the ground for affordable handsets at lowest cost possible and reduced network equipment costs.

Fragmentation in band plans in one region creates unnecessary costs. GSMA analysis of economies of scale ([4]) at the handset level showed that fragmentation in the use of the UHF band in a region would significantly increase handset costs whilst also reducing radio frequency efficiency.

Several countries in Asia Pacific are facing the challenge of limited bandwidth available in other internationally harmonised mobile bands such as the 900, 1800 and 2100 MHz bands where economies of scale have allowed for lowest possible handset cost (and most efficient roaming opportunities). Combined with the rapid roll-out of mobile networks and extensive subscriber growth in many of the markets, this leads to a situation where making maximum spectrum available in the UHF band is of utmost importance.

7.3 Overall Survey of Spectrum and Common Mobile Technologies

During the last three decades of modern mobile communications and shifts of management paradigms, a certain pattern has emerged where technologies or families of technologies have clustered in certain frequency bands in the different regions. ‘Pattern’ may be the most appropriate term, since the situation is characterised by considerable variation and since frequency bands that are fully harmonised and technology specific over complete regions or even worldwide are rare.

To give a detailed survey over which technologies have clustered in which frequency bands in every major and medium sized market in the world would by far exceed the limits of this article. However, an overall table comprising the most significant clusters of frequency bands <–> technology for mobile communications – primarily in Europe but also to some

Frequency band – common term	Common technologies	Regions
450 MHz band (eg. 453-457.5 / 463-467.5 MHz)	NMT analogue, today CDMA 450	The 450 MHz band is not harmonised in any region, but scattered reservations for mobile communications occur in all regions except the US.
Digital dividend or 800 MHz band (eg. 790-862 MHz	LTE will probably be the most popular technology when the digital dividend is opened	Europe seems to be the most harmonised region in terms of management of the dividend. In both the Americas and in the Asia there will be countries that will come close to the CEPT recommendation for management of the dividend, but those regions may not be considered to be harmonised.
900 MHz band (880-915 / 925-960 MHz)	Up to now and in Europe: GSM. The frequency band is currently subject to a refarming that will make licenses technology neutral	The 900 MHz band has not been subject to the same harmonisation in the Americas or Asia, as has been the case in the rest of the world. However, several mobile technologies are implemented in frequency bands close to the 900 MHz band in certain of the two regions, eg. the CDMA technology in the 825-845 / 870-890 MHz band. Some countries in Eastern Europe and Africa deploy CDMA systems in this band.
1800 MHz band (1710-1785 / 1805-1880 MHz	Up to now and in Europe: GSM. The frequency band is currently subject to a refarming that will make licenses technology neutral	In the US: 1850-1910 / 1930-1990 MHz is in many states used by the so-called PCS-1900 technology (GSM in the 1900 MHz band). In major parts of Asia the 1800 MHz band is used in exact the same way as in Europe. The processes of refarming have however not come as far as in Europe.
2.1 GHz band (1900-1980 / 2110-2170 MHz)	WCDMA is used in the whole of Europe. CDMA 2000 is used in some parts of the Americas and Asia, but not on the same scale as WCDMA	Harmonised for Europe and to some extent Asia. Reservation is slightly modified in the US due to eg. giving priority to satellite communication in some of the sub-bands.
2.6 GHz band (2500-2690 MHz)	Technology neutral, most likely LTE	CEPT band plan harmonised in most of Europe and Asia. This is a frequency band used for WiMAX in the US.
3.5 GHz band (3400-3600 MHz)	Technology neutral, 'fixed WiMAX' (IEEE 802.16d) most frequently used technology	Global harmonisation.

Table 2 A survey of the most common technologies for mobile communications and in which geographical areas and frequency bands they are deployed, primarily in Europe

extent outside Europe – may be useful. This is given in Table 2.

8 Future Perspectives

In the future, new technologies appear which not only evolve along the traditional paths towards higher bitrates and more compact user equipment. They also bring features which will inevitably change the way spectrum is awarded, managed and utilized. Cognitive Radio systems (CR), Software Defined Radio (SDR) and LTE-Advanced (LTE-A) are such technologies.

8.1 CR and SDR

The cognitive radio observes its environment and combines these observations with its internal rules (in terms of available radio resources, applicable spectrum rules, user needs and preferences, operational cost of a service etc.) in order to provide service according to the user needs and preferences. In addition, the radio is also capable of learning from its past actions and experience. In order to achieve this, SDR is regarded as an important enabler of CR. The SDR allows the radio operating parameters such as frequency range, modulation type, or output power to be set or altered by software, thereby acting swiftly to the observed environment and other input parameters.

The focus of the use of CR is very much on *opportunistic spectrum access* whereby cognitive radios may identify unused portions of spectrum and use that spectrum without affecting existing users. The use of so-called white spaces (frequencies allocated to broadcasting services, but not used locally) in the US for provision of wireless broadband services is so far the most prominent example of this and has caused quite a lot of debate especially between the 'White Space Coalition', a group including Microsoft, Google, Dell, HP, Intel and Philips, and the various broadcasting associations.

CR should also be regarded as a tool to regulate spectrum access within a licensed band among the licensed user(s) only, and in this context CR is less controversial. CR is in other words expected to handle spectrum sharing management in a more autonomous way and thereby provide for a higher utilisa-

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tion of spectrum. In the longer term, it may even take on some of the current responsibilities of the national regulators, but at the same time it seems obvious that the regulators will be faced with a range of new challenges in order for this regime to work in a fair way for all parties.

Among the important issues currently being worked on are the technical principles for the user terminals to obtain the necessary radio-environmental information. Three main principles have emerged:

- *Sensing:* The terminal obtains a real-time 'map' of the radio environment;

- *Databases / Geo-Location:* An available database of the frequencies which can be used at certain locations, as well as the applicable rules;

- *Cognitive pilot channel (CPC):* A dedicated common carrier, providing frequency usage information for the intended band.

Among these principles, sensing seems to lose momentum while the other two principles or even a combination of the two are gaining ground. This opens up for questions around the responsibility and ownership of these required common infrastructure elements, financing and proper business models, forward compatibility with future technologies, European or even international interface standards etc. etc. Also, once certain systems become reliant on opportunistic spectrum access it may be difficult to reverse this process once 'unused' spectrum is needed by the primary users.

Of course, research communities regard CR and SDR as attractive and interesting challenges for technology development, the regulators have expectations towards better spectrum efficiency and a higher degree of autonomy among spectrum users and the operators/existing licence holders on their hand call for caution. Even if the cognitive radio technology looks promising for specific applications and uses, deployment maturity is not yet given and needs to be proven. However, all parties agree that CR and SDR as emerging communication technologies will be important tools in the future to address the spectrum scarcity challenges.

8.2 LTE-A

As mobile broadband technologies provide for increasingly higher bitrates, the requirements for spectrum bandwidth inevitably increase. Optimum performance of LTE is reached using carrier bandwidth of 20 MHz and the next generation LTE, LTE-A calls for a stunning 100 MHz of bandwidth in order to demonstrate optimum performance. For maintaining the mobility of such systems, deployment is still envisaged in the lower frequency bands and it will represent a huge challenge finding this much bandwidth in this part of the spectrum. To somewhat ease this challenge, LTE-A introduces new interesting principles in terms of how the necessary spectrum is located. It does not require a contiguous block of 100 MHz in order to operate, but allows for drawing the operation from multiple non-contiguous blocks of spectrum across multiple bands (eg. 900 MHz, 1800 MHz, 2.6 GHz) or within the same band and eventually even across multiple bands.

This opens up for really interesting possibilities but disregard all clever technical attempts and techniques to utilise the most attractive bands in optimal ways, the hard facts of spectrum availability make the practical possibilities for multiple network operators and infrastructure competition more and more difficult. Consolidation among network operators through network sharing and competition more focused on the service provision level may likely be the result.

9 Final Remarks

Access to broadband, and in particular mobile broadband, will in most countries impact the way people live, the way people work and may also have an impact on the quality of education in areas where there is a lack of resources designated for education, such as skilled teachers and study material. These goals may be reached by increasing the broadband penetration in different areas of the world where there is a lack of sufficient infrastructure to provide high quality internet services. It is therefore essential that governments acknowledge the value the mobile industry can create to society by rolling out mobile networks and provide affordable data services to consumers. The mobile industry is dependent on access to a sufficient amount of harmonised spectrum in order to deploy mobile broadband. The way spectrum is managed nationally is therefore vital to give the right incentives for innovation and investment in a country. Sustainable regulatory conditions that are transparent, coherent and predictable, and that also to some extent allow for a market based approach to spectrum management will presumably facilitate a broader range of technologies and services to be provided to consumers.

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