Technische Universität Braunschweig
Institut für Nachrichtentechnik

Technische Universität Braunschweig | Institut für Nachrichtentechnik
Schleinitzstraße 22 | 38106 Braunschweig | Germany

Federal Ministry of Economics and Technology
Division I C 4
Mr Baumeister

53107 Bonn

Technische Universität Braunschweig
Institut für Nachrichtentechnik

Schleinitzstraße 22
38106 Braunschweig
Germany

Prof. Dr.-Ing. Thomas Kürner
Prof. Dr.-Ing. Ulrich Reimers

Tel. +49 (0) 531 391-2480
Fax +49 (0) 531 391-5192
u.reimers@tu-bs.de
www.ifn.ing.tu-bs.de

Date: 21 January 2013

A study of future spectrum requirements for terrestrial TV and mobile services and other radio applications in the 470-790 MHz frequency band, including an evaluation of the options for sharing frequency use from a number of socioeconomic and frequency technology perspectives, particularly in the 694-790 MHz frequency sub-band

Final report

Prof. Dr.-Ing. Thomas Kürner

Prof. Dr.-Ing. Ulrich Reimers

Dr.-Ing. Kin Lien Chee

Dipl.-Ing. Thomas Jansen, M. Sc.

Dipl.-Ing. Frieder Juretzek

Dipl.-Ing. Peter Schlegel

On 27 August 2012, the Federal Ministry of Economics and Technology officially commissioned the Institut für Nachrichtentechnik (Institute for Communications Technology) at the Technische Universität Braunschweig with completing an expert study and analysis (Project code: 85/12) as titled above. This report presents the results of this study.

Executive Summary

During the World Radiocommunication Conference (WRC) in 2012, it was decided that one of the agenda items for WRC 2015 would focus on the possible future use of the frequency band 694 MHz to 790 MHz for mobile services. This expert report addresses this topic by initially analyzing the outlook for the terrestrial TV broadcasting that has occupied this frequency band to date. Three possible scenarios are developed. Of these, only two are considered realistic: "Switchover from DVB-T to DVB-T2" and "Phasing out of terrestrial TV broadcasting".

If there is a **switchover from DVB-T to DVB-T2**, it will be possible to use part of the 700 MHz band for other services, provided this is coordinated successfully with other countries outside Germany. This migration could happen in urban agglomerations starting around 2018 and be rolled out throughout Germany from around 2020. As part of the migration, hundreds of TV broadcasting stations would have to be modified. The concerns of cable operators who are currently operating networks that support both TV and Internet services in the frequency band under review must also be taken into consideration. Operators of PMSE systems require frequency allocations outside the UHF band. For this scenario, the report proposes band plans that take account of mobile services and services for Public Protection and Disaster Relief (PPDS), and that provide for coexistence between various radio applications.

The report also proposes band plans if **terrestrial TV broadcasting is phased out**: under certain conditions, this phase-out may already be complete by 2019. If terrestrial TV broadcasting comes to an end, there will be multiple consequences - some obvious, others less so. In addition to the international coordination already mentioned and consideration of the concerns of cable network operators, financing models would be needed, for example, to support the future of private and public radio broadcasters, since these would lose their shared access to TV transmitter masts etc. In this case, operators of PMSE systems require specially reserved frequency ranges. For broadcasting live video to portable and mobile receivers (including in-car receivers), we will require innovative solutions beyond the current state-of-the-art for mobile communications. To meet this challenge, broadcasting of live video must be enabled over and above the data volume limits specified by the mobile network operators in their customer agreements. It may also need to be linked to a 'must-carry' rule and many other commitments.

The expert report concludes by outlining some **research approaches** that could tackle the increasingly pressing issue of cooperative or co-primary use of terrestrial frequencies for broadcasting and mobile services. It also calls for research and development support in this important area.

Contents

1 Introduction

1.1 Specific tasks

On 27 August 2012, the Federal Ministry of Economics and Technology officially commissioned the Institut für Nachrichtentechnik (Institute for Communications Technology) at the Technische Universität Braunschweig with carrying out an expert analysis and report (project code: 85/12). The project was entitled "A study of future spectrum requirements for terrestrial TV and mobile services and other radio applications in the 470-790 MHz frequency range, including an evaluation of the options for sharing frequency use from a number of socioeconomic and frequency technology perspectives, particularly in the 694-790 MHz frequency sub-band". The investigation was to focus primarily on the following items listed in the tender documents:

- Investigate the use by terrestrial TV broadcasts and wireless production technologies
- Investigate expanded usage for mobile services
- Investigate usage by broadband applications for Public Protection and Disaster Relief (PPDS)
- Examine hybrid approaches for sharing the spectrum, including dynamic broadcasting in particular

An interim presentation on our investigations was held for interested parties during the "Mobile Media 2020" conference at the Federal Ministry of Economics and Technology (BMWi) on 12 November 2012. The Ministry also presented a discussion paper titled "Mobile Media 2020" [64] as part of the event. Afterwards, all participants were invited to comment on both the discussion paper and our interim presentation.

This report presents the results of this expert investigation. It also refers, in particular, to points raised in the "Mobile Media 2020" discussion paper and the comments submitted.

1.2 Methodology

We conducted our investigations in three stages:

- First, the spectrum requirements of individual services in the UHF band were analysed. This stage of the investigation focused on terrestrial TV broadcasting (Chapter 2), PMSE (Program Making and Special Events; Chapter 3), broadband coverage through commercial mobile services (Chapter 4) and broadband applications used for Public Protection and Disaster Relief (PPDR), and also by the military services and operators of critical infrastructure (Chapter 5).
- The second stage addressed new ways of sharing the spectrum between terrestrial TV and mobile networks, which were developed at the Institute for Communications Technology. These new approaches are described in Chapter 6.

- Based on the results of Chapters 2 to 6, a number of measures and recommendations were compiled and specific band plans developed for different scenarios (Chapter 7).

1.3 Differences between mobile/broadcasting services

Time and time again, discussions within the industry reveal that the stakeholders in mobile services and in radio and TV services (grouped together as broadcasting here) neither recognise nor acknowledge the basic differences between their respective worlds. This section outlines some of these differences.

A mobile network operator acquires a particular frequency block that is allocated to offering its service only. The service offered is a mode of communication, rather than provision of particular content. Service users expect to have access to a particular data transfer rate or quality of service, but are not concerned by the particular frequency or network cell used to provide the service. If the frequency switches, e.g. at the boundary of a network, the service is transferred to another frequency belonging to the particular network operator within the frequency allocation (the network operator’s SIM card is fitted in the user’s end device). The communication service is thus maintained.

However, a broadcast network operator not only uses the frequencies allocated for broadcasting to provide a mode of communication, but also to broadcast specific content. The suppliers of this content are therefore competing with each other for this frequency spectrum, even if they are clients of the same broadcast network operator. Each frequency thus carries separate content. A change in frequency automatically results in a change in content. If three, or even seven TV channels can be received at a particular location, 12 or 28 different programmes are transmitted via these.

Customers usually purchase their end devices directly from the mobile network operator. This cost of these end devices is usually subsidised in the overall price, since purchase is generally tied, for example, to a two-year user contract. Customers therefore do not know the real market price of their end devices. They usually receive a new device after two years, accompanied by a new contract.

In contrast, the purchasers of a TV receiver are legally obliged to pay the user licence fee (Rundfunkbeitrag) to the public broadcasting corporations. They purchase the end device without subsidy and pay the going market price. There is then no incentive to replace this end device unless it develops a fault, or unless the user wishes to avail of HDTV. The average service life of a TV receiver ranges from five to ten years. Devices purchased from 2011 onwards generally incorporate so many options (HDTV, 3DTV, HbbTV etc.) that most users would not be expected to need a new purchase in the foreseeable future. For this reason, any change to the resources for TV broadcasts potentially affects millions of people who have privately invested in end devices.

2 Spectrum requirements for terrestrial TV broadcasting

This chapter begins by analysing the current situation with regard to terrestrial TV broadcasting in Germany. It focuses, in particular, on current usage of the frequency range between 694 MHz and 790 MHz. Next, it presents the DVB-T2 system, which if introduced, will enable the enhancement of terrestrial TV broadcasting, for example, for launching HDTV. This is followed by an examination of alternative scenarios for the future use of the UHF range for terrestrial TV broadcasting. The chapter closes with recommendations for the future of terrestrial TV broadcasting.

2.1 Terrestrial TV broadcasting with DVB-T

2003 marked the beginning of the gradual, region-by-region replacement of analogue terrestrial TV by DVB-T [1] in Germany [2]. This changeover was completed by 2008. By this time, 488 DVB-T broadcasting transmitters were in operation throughout Germany [3].

While the regional broadcasting stations of ARD initially insisted on continuing to use the VHF frequency range for DVB-T, transmitters operating within that frequency range were later taken out of service due to the excessive impact of man-made noise on this range. As a result, all DVB-T transmitters are now concentrated within the frequency range of 470 to 790 MHz. This range comprises 40 frequency channels (channels 21 to 60), each with a channel bandwidth of 8 MHz. Twelve channels (channels 49 to 60) are within the frequency range of 694 MHz to 790 MHz, which is of particular interest in connection with WRC 2015. These represent 30% of the resources currently used for DVB-T broadcasting. The current list of DVB-T transmitters, sorted by Federal State and including details of how each frequency channel is allocated to the transmission of programming by the various broadcasters, is provided in [4].

Of the DVB-T transmitters that are currently operational in Germany, 139 operate within the channels 49 to 60 [5]. These transmitters have an ERP (effective radiated power) of up to 100 kW. This represents a key difference between the current situation and the situation that prevailed in the 791 MHz to 862 MHz frequency range prior to the “digital dividend”, i.e. the switchover from analogue to digital broadcasting. While a relatively small number of DVB-T transmitters operated within that range, intensive use is currently being made of channels 49 to 60.

The map in Figure 2-1 illustrates the situation regarding DVB-T broadcasting in Germany in 2012 [6]. While the public broadcasters ARD and ZDF both broadcast programmes to rooftop aerials in almost every part of the country, private broadcasters are mostly limited to broadcasting in large urban areas. This results in “TV white spaces”, both large and small, within the UHF frequency range. This term describes regional gaps that arise between the channels actually used in the frequency range that has been allocated for TV broadcasting, which could, in certain circumstances, be used for other wireless applications without interfering with TV reception [7]. Figure 2-2 shows these TV white spaces, using the example of mobile outdoor reception, with a realistically calculated receiver sensitivity threshold of -72 dBm [8] and taking account of the broadcasters transmitters broadcasting from neighbouring countries (as documented by the Federal Network Agency) and other constraints. It does not take account of the special features of signal transmission over water, which, in the case of Mecklenburg-Vorpommern in particular, would exert a particular influence on the number of TV white spaces. The number of channels available as TV white spaces indicated on the scale next to the map should not be overinterpreted because it naturally depends on the sensitivity of the TV receiver used. These figures nonetheless demonstrate that untapped frequency resources already exist within the UHF band as a result of disparities in the use of the available frequency channels across the various regions, as documented in Figure 2-1.

Figure 2-1: DVB-T reception throughout Germany (May 2012)

In Germany, DVB-T typically enables the simultaneous transmission of four programming services with SDTV quality (Standard Definition TeleVision) in a single channel with a net data rate of 13.27 Mbps. However, Berlin, for example, has a DVB-T variant with a net data rate of 22.12 Mbps, which enables the transmission of programming services broadcast by six TV stations and seven radio stations in a single channel.

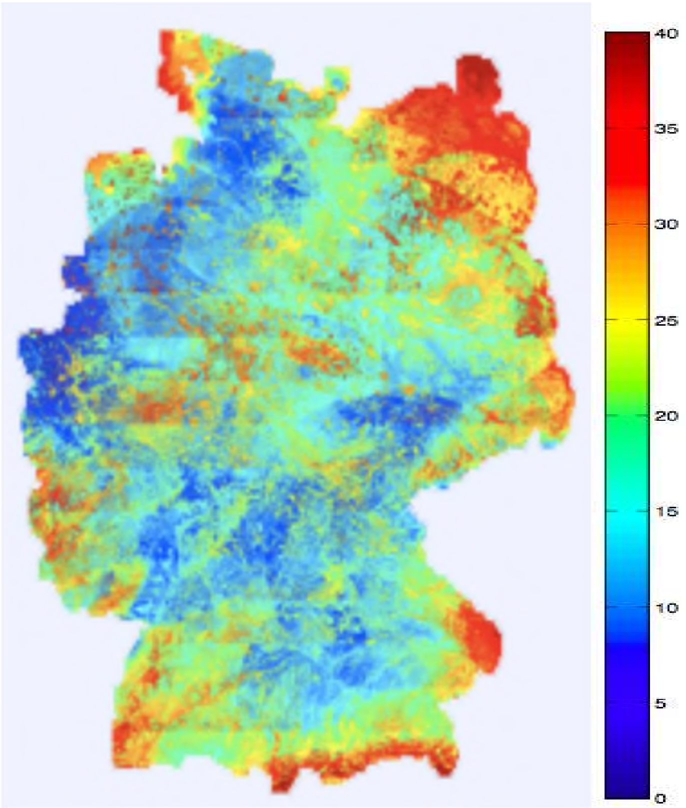

Figure 2-2: TV white spaces in the UHF band in Germany

Consequently, there are significant differences between individual areas in terms of the number of programming services that can be received, as private broadcasters normally only use DVB-T to broadcast their programmes in large urban areas. This is why the number of programming services that can be received via DVB-T is just 9 in Mecklenburg-Vorpommern, but almost 40 in Berlin [4]. The use of DVB-T by German households is documented on an annual basis in the Digitalisation Report published by the state media authorities. The following graphic (Figure 2-3is taken from the 2012 Digitalisation Report [9].

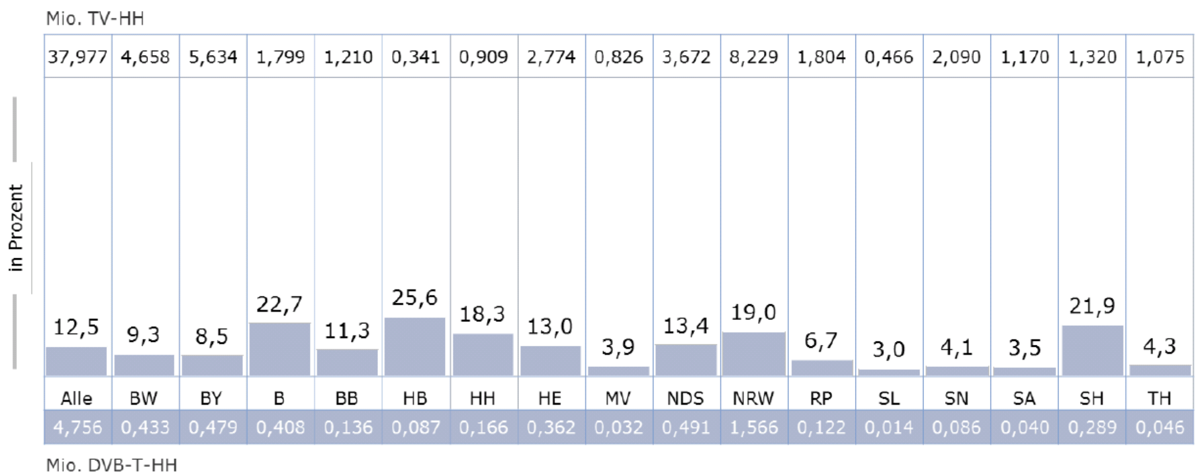

Figure 2-3: Use of DVB-T by Federal State

One important finding that can be extrapolated from the data shown in Figure 2-3 is that the percentage use of DVB-T only exceeds single figures in areas where programming services broadcast by both public and private broadcasters can be received. If private broadcasters were to decide to cease terrestrial TV transmission, this would lead to a huge drop in usage. The 2012 Digitalisation Report also reveals that approximately 4.8 million of Germany's 38 million households were using DVB-T in 2012. This represents an increase of about 0.3 million households compared with 2011. Of these DVB-T households, approximately 3.7 million use DVB-T on their main television set, while around 1.1 million only use it on additional sets in the home. However, DVB-T is also used on PCs and laptops, as well as on conventional TV sets. Of the approximately 5.8 million households that, according to the 2012 Digitalisation Report, also use PCs or laptops to watch TV, at least 33.7%, or around 2 million households, use DVB-T. The German TV Platform estimates that approximately 1 million German cars are now equipped with DVB-T receivers.

2.2 Perspectives on the introduction of DVB-T2

DVB-T2 is a second-generation system for terrestrial broadcasting, which offers significant enhancements compared with DVB-T. For example, DVB-T2 enables a reduction in the transmission power required in terrestrial networks, while retaining the data rate per channel that is already used with DVB-T. Alternatively, it also allows for a significant increase in the data rate per channel while retaining the transmission power used today for DVB-T. In addition to many other innovative features, DVB-T2 offers “Multiple Physical Layer Pipes” (MPLP). With MPLP, signals of varying robustness can be transmitted within a single channel. One advantage of this feature is that some programming services can be received on devices with a small rod antenna, while sophisticated antennae are required to receive other programming services that are broadcast in the same frequency channel. DVB-T2 enables the implementation of single-frequency networks (SFNs), in which the inter-transmitter distance is significantly larger than in current DVB-T networks. DVB-T2 also allows for TV reception in cars travelling at high speed, as well as many other innovations.

DVB-T2 underwent extensive testing as part of the DVB-T2 trial project conducted in northern Germany. The authors of this report acted as technical directors for the trial. The final results of the project are documented in the final report [10]. Based on these findings, the public and private broadcasters, network operators, media institutes and manufacturers involved in the project agreed on three possible scenarios for the introduction of DVB-T2. These are described below:

Scenario 1: This scenario focuses on the portable and mobile reception of SDTV programming services. DVB-T2 mode [16 k FFT, 16 QAM, code rate 3/5] is used in this case. A signal-to-noise ratio (S/N) of 11 dB is required to guarantee stationary and portable reception, while the S/N must be 14 dB to guarantee mobile reception. The available data rate is 14.8 Mbps, of which 14.1 Mbps remains for the multiplex as a whole after subtracting the data rate of 0.7 Mbps that is required for programme-specific information/service information (PSI/SI) and null packets. Depending on the specific decisions made by broadcasters, this data rate is sufficient to transmit 7 or 8 SDTV programmes if H.264/AVC MPEG-4 part 10 video coding is used.

Scenario 2: This scenario envisages broadcasting of SDTV with enhanced picture quality (SDTV+) to stationary, portable and mobile end devices. DVB-T2 mode [16 k FFT, 64 QAM, code rate 3/5] is used in this case. A signal-to-noise ratio of 16.4 dB is required for stationary and portable reception, or 24.4 dB for mobile reception. The available data rate is 22.2 Mbps, of which 21.5 Mbps remains for the multiplex as a whole after subtracting the data rate of 0.7 Mbps that is required for PSI/SI and null packets. Depending on the specific decisions made by broadcasters, this data rate is sufficient to transmit 7 or 8 SDTV+ programmes if H.264/AVC MPEG-4 part 10 video coding is used. Alternatively, 4 or 5 SDTV+ programmes and one HDTV programme could also be broadcast in a single channel in this scenario.

Scenario 3: This scenario focuses on broadcasting to stationary and portable HDTV end devices. The DVB-T2 mode [32 k FFT, 64 QAM, code rate 2/3] is used in this case. A signal-to-noise ratio of 17.0 dB is required to guarantee stationary and portable reception. The available data rate is 27.3 Mbps, of which 26.6 Mbps remains for the multiplex as a whole after subtracting the data rate of 0.7 Mbps that is required for PSI/SI and null packets. Depending on the specific decisions made by broadcasters, this data rate is sufficient to transmit 3 or 4 HDTV programmes if H.264/AVC MPEG-4 part 10 video coding is used.

The flexibility of DVB-T2 and the toolbox-style nature of the system are reflected in the many combinations of service scenarios and parameter sets that exist in theory and in practice.

A decision on the introduction of DVB-T2 in Germany has yet to be made. However, there were increasing indications over the months of October and November 2012 in particular that DVB-T2 would indeed be launched in Germany (see, for example, [11]).

2.3 Spectrum requirements for 2020

At present (end of 2012), it is impossible to predict with certainty what lies ahead for terrestrial TV broadcasting in Germany. We can therefore only estimate what the actual spectrum requirements are likely to be based on various scenarios. With each of the variants set out below, it must be remembered that the use of the various channels available for TV broadcasting is regulated by international agreements and that Germany is bound to abide by the terms of these agreements. In some of Germany’s neighbouring countries, terrestrial broadcasting continues to play an important role as the primary broadcasting medium for TV programming. It is likely that these countries will continue to use terrestrial broadcasting, regardless of any possible decisions made in Germany. As we cannot foresee when or even if Germany's neighbours will be ready to change their existing arrangements, it must be borne in mind that the scenarios outlined here will only be possible if coordinated at an international level.

These scenarios do not incorporate innovative approaches such as dynamic broadcasting or the use of broadcast networks as overlay networks via cellular networks. Chapter 6 of this report discusses these approaches.

2.3.1 Continuation of DVB-T broadcasting in its current (2012) scope

This scenario assumes that broadcasters will continue DVB-T broadcasting in its current scope. In this case, urgent consolidation of the usage of available channels would be required, since this currently differs from one region to the next. As part of the planning of DVB-T broadcasting in Germany, private broadcasters demanded that the frequency spectrum allocated to them be equivalent to that allocated to public broadcasters [2]. In reality, however, these frequency allocations are still not being used to full capacity. The channel allocated to the operation of DVB-H (broadcasting handheld devices) also remains unused. The replanning of DVB-T broadcasting in Germany will reduce the spectrum requirements for terrestrial TV transmission. As-yet unpublished findings of a working group set up by the Federal Network Agency ("UHF klein") indicate that, with a small number of exceptions, consolidation within the channels 21 to 28 will be possible. Therefore, it should, in principle, be possible to free up channels 50 to 60 for other uses in the medium term. Channel 49 is required for DVB-T broadcasting in certain locations. In these areas, channel 50 will probably have to be kept as a guard channel (where necessary) and will not be reallocated for new uses. In the remaining regions, channel 49 will have to be defined as a guard channel (where necessary).

The continuation of DVB-T broadcasting in its current scope carries the risk that terrestrial TV transmission will begin to lose acceptance in the medium term, even in regions where intensive use is currently made of DVB-T (see Figure 2-3). In its press release of November 20, 2012, the German Association for Consumer and Communications Electronics (*Gesellschaft für Unterhaltungs- und Kommunikationselektronik*, *gfu*) predicted that 10 million (presumably fully) HDTV-compatible television sets will have been sold in Germany in 2012 alone. The number of households that are ready to receive HDTV is growing all the time. And, we can assume that the owners of these devices will increasingly switch to a transmission medium that actually offers HDTV quality. As DVB-T cannot do so, the number of DVB-T users is likely to decrease. Consequently, DVB-T transmission may have become economically unfeasible by 2020.

The requirements of broadcasters or network operators if they continue with DVB-T transmission in its current scope (as at 2012) are unknown.

2.3.2 Switchover from DVB-T to DVB-T2

In a press release dated September 12, 2012, ARD explained that it planned to use DVB-T2 to enable portable and mobile reception. The broadcaster stated that its aim is to achieve HDTV picture quality for linear broadcasting. It plans to switch to DVB-T2 in the period 2016 to 2018 at the earliest [10]. It is reasonable to assume that ZDF will take a similar approach. To date, private broadcasters have not yet made any concrete statements with regard to the introduction of DVB-T2. Media Broadcast GmbH suggests that it may launch DVB-T2 broadcasting in a single channel in early 2014. This is presumably the channel that was originally allocated to broadcasting to handheld devices (DVB-H). The broadcasting is to begin in the regions where programming services from both public and private broadcasters are currently received via DVB-T [12]. The programmes to be transmitted via DVB-T2 will be those offered by public broadcasters and will have HDTV quality. Media Broadcast foresees that the changeover of its current DVB-T offering to DVB-T2 will be completed over the course of 2016, following a relatively short Simulcast (simultaneous broadcast) phase. This means that DVB-T2 signals would be transmitted in six or seven channels by around the middle of 2017. In this case, the spectrum requirements would be the same as those 2.3.1that would apply if DVB-T transmission were to be continued (see Section 2.3.1).

One problem associated with the introduction of DVB-T2, which has been recognised for quite some time, is that DVB-T2 can be used for a range of different purposes, as described in Section 2.2). 2.2. Some players in this field advocate that DVB-T2 should be used for the transmission of HDTV programming. If we assume that four HDTV programmes are transmitted in each channel (see 2.2, Scenario 3), this would mean that spectrum requirements would be no different from those that currently apply in the case of DVB-T broadcasting, at least initially. However, we must consider whether all programming that is currently broadcast via DVB-T will be offered in HDTV quality in the future. In addition, we can safely assume that private broadcasters will also implement the HD+ concept already in use for satellite transmission for their terrestrial broadcasting. Once this happens, the range of programming that can be received in unencrypted format will be limited to the programming services provided by public broadcasters. In this case, viewers would also have to pay a specific charge for their use of DVB-T2 to continue enjoying the range of DVB-T programming currently on offer in large urban areas. The question also arises of whether current viewers who are interested in HDTV may already have switched to a different broadcasting medium (cable, satellite or IPTV) by the time that HDTV via DVB-T2 is introduced ((see, for example, the forecast sales figures for HDTV-compatible receivers in Section 2.3.1).

2.3.3 Phasing out of terrestrial TV broadcasting

By all accounts, existing contracts between private broadcasters and Media Broadcast GmbH in relation to the broadcasting service provider’s transmission of their programming services via DVB-T are set to expire by the end of 2014. According to information we have received by word-of-mouth from the parties involved, negotiations are currently underway with a view to continuing transmission beyond the end of 2014. If these negotiations fail to result in an extension of DVB-T transmission, a significant drop in the acceptance of DVB-T can be expected to occur as early as 2015, even in the Federal States where, according to Figure 2-3Figure 2-3 usage levels are particularly high. The economic viability of terrestrial broadcasting is therefore in question, even for public broadcasters. In the spring of 2015, these broadcasters will be required to report their financial requirements for the period 2017 to 2020 to the Commission to Define the Financial Needs of Public Broadcasting Stations (KEF). If private broadcasters were to opt out of terrestrial TV broadcasting, it is doubtful that the KEF would be able to recognise the funding of a continuation of DVB-T broadcasting for the entire period as financially viable. This could, in turn, spell the end of terrestrial TV broadcasting by, say, the end of 2018.

Such a development would have a significant impact on terrestrial radio broadcasting, as radio broadcasting stations are frequently operated within the same facilities used for DVB-T broadcasting. If DVB-T transmission were to cease, radio broadcasters would have to carry the total costs of operating these facilities, which they currently share with their TV counterparts. It is conceivable that the future users of these frequencies, which would no longer be home to TV transmissions in this scenario, would be obliged to pay a share of radio transmission costs.

Following a potential future cessation of terrestrial TV broadcast, TV transmitters could possibly be used to transmit broadcast data (audio, video, data) in the form described in Chapter 6 as "Tower Overlay over LTE-Advanced". With this approach, the transmitters would not, in principle, lose their function. Rather, their current use for traditional TV broadcasting would, in future, be replaced by the transmission of media content to mobile end devices, such as smart phones and tablets.

2.4 Recommendations for the future of terrestrial TV broadcasting

Given the current uncertainty (end of 2012) in relation to the continuation of terrestrial TV broadcasting by private broadcasters, the recommendations set out below are an attempt to identify which of the three scenarios described earlier represents the best possible usage of the UHF spectrum, while also enabling terrestrial transmission of live video. The long-term continuation of DVB-T broadcasting in its current scope (as at 2012) cannot be recommended. Therefore, we must look instead to a switchover from DVB-T to DVB-T2 or, following the possible end of conventional TV broadcasting, to innovative concepts for transmitting live video, in particular to mobile and portable end devices. However, it is ultimately up to the broadcasters to decide whether to offer HDTV or SDTV+ in the event of a switchover to DVB-T2, and whether to transmit their programming services in unencrypted (as has already been selected by public broadcasters) or encrypted form.

If the decision is made to migrate to DVB-T2, this can be expected to occur as of 2016, possibly with a transition phase using the channel allocated to DVB-H (see Section 2.3.2). In larger urban areas, the migration will be completed by 2018. By that time, a reduction in the frequency range required for terrestrial TV broadcasting to channels 21 to 48 only (or possibly also channel 49 (see Section 2.3.1) will be possible, at least in these areas. Outside of large urban areas, the migration could, in certain circumstances, take up to two additional years (i.e. until 2020) to complete. As of 2019, the channels vacated by TV transmission will be available for alternative radio applications - with this possibly occurring gradually, region by region. The use of these channels for other purposes will need to take account of the potential disruption of TV cable networks. In connection with this, consideration must be given to the possibility of placing tighter restrictions on the permitted uplink and downlink transmission power used for alternative radio applications in large urban areas, i.e. in the areas where cable networks are particularly well developed, compared with restrictions in other areas, which will potentially have larger network cells.

If terrestrial TV broadcasting as we know it is to cease, for example, by the end of 2018, we recommend taking the innovative approach of using a tower overlay over the cellular mobile networks as described in Chapter 6 or a comparable approach in order to enable the efficient broadcasting of live video to mobile and portable end devices. One advantage of such approaches is that the mobile network operators who will potentially be able to use parts of the UHF spectrum as of 2019 will not have to transmit live video in multiple networks or, in extreme cases, in each mobile network in parallel. We also recommend that suitable layers be used to ensure that the transmission of live video is possible outside of the data volume limits defined by mobile network operators in their customer agreements. The data volume limits that typically apply at the present time (e.g. 15 GByte per month) could be exceeded within just a few hours with the reception of high-quality live video. Finally, the option of imposing a must-carry obligation on mobile network operators for certain live-video offerings (TV programmes) should be considered.

Should conventional terrestrial TV broadcasting cease to exist, an appropriate way of providing the operators of PMSE services with a protected spectrum for their services must be found.

3 Spectrum requirements for PMSE (Program Making and Special Events) systems in the UHF band

This section begins by looking at the current situation regarding frequency usage for PMSE systems. Next, we define the constraints that apply to spectrum allocation for PMSE systems. Finally, we present various possible scenarios for future use of the UHF band, which take account of PMSE systems.

3.1 Use of PMSE devices

PMSE systems include wireless microphones, radio technology for stage direction and remote control, in-ear monitoring equipment, conferencing systems, as well as equipment for the hard-of-hearing and wireless audio tour guide systems. PMSE systems are primarily used for professional event engineering and event production in the performing arts sphere and in the broadcasting field. As such, they represent important resources in the cultural and creative economy, which contributed an estimated 63.7 billion euros to gross added value in 2010 [13]. PMSE systems can be divided into mobile and fixed systems, with the majority falling into the fixed category. Mobile equipment is used on-location on a temporary basis for the duration of the event. These events include television productions, sporting events, elections, concert tours and events in the entertainment sector. Fixed PMSE systems used in studios and in venues such as university lecture halls, music halls, theatres, churches or conference rooms, are permanent installations, which are either in constant use or operated on a daily basis. The following overview illustrates how many PMSE channels are typically used for various events.

- Up to 50 PMSE channels are required for standard uses, e.g. for theatrical productions, musicals, concerts and conferences, as well as in universities, churches, hotels, schools etc., for example:
  - Hanover Opera House 32 UHF PMSE channels
  - TU Braunschweig: 32 UHF PMSE channels (in 2010)
- For large-scale events, such as TV, film and show productions or very large musical and theatrical productions, approximately 50 to 150 PMSE channels may be used.
  - Hanover Theatre: 62 PMSE channels
  - Musicals - "Mama Mia" or "The Lion King": 60 and 82 PMSE channels respectively
- For extremely large events, more than 150 PMSE channels are used, for example:
  - State parliament elections in Hanover, 2008: 380 channels [14]
  - State election in Hamburg, 2008: 309 channels [14]
  - Eurovision Song Contest 2011: 212 channels were coordinated. According to the spectrum-usage recordings taken by the DKE (the German

Commission for Electrical, Electronic & Information Technologies of DIN and VDE), during the event, the maximum number of channels operating simultaneously at any one time was 126. Almost the entire UHF band from 470 – 790 MHz was occupied by PMSE systems – with the exception of those channels occupied by DVB-T transmissions [15].

- Olympic Games in Sydney: over 800 channels
- Olympic Games 2012 in London: 248.3 MHz of spectrum in the UHF band was used for PMSE systems. A total of 6,052 wireless microphones and 1,468 in-ear monitoring systems were used during the Games [16].

PMSE devices are also used in many public, government-funded institutions serving the common good in the spheres of science, education, culture and the arts [17].

A study by the University of Hanover calculated a daily requirement of 96 MHz for PMSE devices, based on an urban scenario in the centre of Berlin [18].

Overall, spectrum usage for PMSE applications is on the rise. The bandwidth of a PMSE audio channel is, with very few exceptions, 200 kHz, regardless of the technology used. A separate 200-kHz channel is required for each PMSE transmission path.

3.2 Current spectrum usage for PMSE systems

At present, PMSE devices are primarily used in the UHF spectrum as secondary users alongside terrestrial broadcasting. Frequency is allocated at national level. As a result of the digital dividend, two frequencies ranges are available for use by PMSE devices in the UHF band from 470 – 790 MHz. According to the Federal Network Agency's Frequency Usage Plan (as at August 2011), the following frequencies are allocated to PMSE devices in the UHF band [19]:

- Radio microphones: 470 – 606 MHz
  One-way transmission of voice, music or other sound signals for use by radio microphones
  Maximum permitted equivalent radiated power: 50 mW ERP
  Channel bandwidth: 200 kHz
  Channel spacing: 25 kHz
  Shared use of TV channels 21 – 37
- Radio microphones: 614 – 790 MHz
  One-way transmission of voice, music or other sound signals for use by radio microphones
  Maximum permitted equivalent radiated power: 50 mW ERP
  Channel bandwidth: 200 kHz
  Channel spacing 25 kHz
  Shared use of TV channels 39 – 60

TV channel 38 (606 – 614 MHz) is not available for PMSE devices because the corresponding frequencies are used in radio astronomy.

Frequency allocation for terrestrial broadcasting in the UHF band:

- DVB-T: 470 MHz – 790 MHz
  Transmission of digital image, sound and data services based on the DVB-T standard
  Channel bandwidth: 8 MHz
  Channel spacing: 8 MHz
  The transmission of broadcasting services takes priority over the transmission of other content (media services, teleservices).

Other allocations for PMSE devices outside of the UHF band under consideration

- Radio microphones: 790 – 862 MHz
  One-way transmission of voice, music or other sound signals for use by radio microphones
  Maximum permitted equivalent radiated power: 50 mW ERP
  Channel bandwidth: 200 kHz
  Channel spacing: 25 kHz
  General assignments: Ruling 91/2005 [20] and Ruling 09/2011[21]
  Usage by radio microphones is assigned a lower priority than usages for broadcasting, fixed service, and wireless network access to telecommunication service offerings.

- Radio microphones: 863 - 865 MHz (SRD band)
  Maximum permitted equivalent radiated power: 10 mW ERP
  Channel bandwidth: 200 kHz (max. 300 kHz)
  Channel spacing: Not specified

General assignment for a limited period until 31/12/2013 (Ruling 68/2003) [22]

- Radio microphones: 1452 -1477.5 MHz (L band)
  Maximum permitted equivalent radiated power: 50 mW ERP
  Channel bandwidth: 50 kHz
  Channel spacing: Not specified
  Broadcasting usages take priority over usage by radio microphones. As part of European harmonisation, new usage options are currently being discussed for the frequency range between 1,452 MHz and 1,492 MHz.

- Radio microphones: 1785 - 1805 MHz (LTE-1800 duplex gap)
  Maximum permitted equivalent radiated power: 50 mW ERP
  Channel bandwidth: Not specified
  Channel spacing: Not specified
  General assignment for a limited period until 31/12/2021 (Ruling 10/2011) [23]

The frequency range 790 – 862 MHz currently contains two blocks with individual assignment and general assignments for PMSE made by the Federal Network Agency. The general assignments were made in the Agency's Ruling 91/2005 (frequency range 790 – 814

MHz and 838 – 862 MHz) for a limited period until 31 December, 2015 and Ruling 09/2011 (frequency range 823 – 832 MHz (LTE-800 duplex gap) for a limited period until 31 December, 2021 [20], [21]. Due to the increasing development of LTE-800 networks and the limited nature of the general assignment in accordance with the Federal Network Agency's Ruling 91/2005 (up to 31 December 12, 2015 only), the 790 – 814 MHz and 838 – 862 MHz frequency ranges are increasingly losing relevance for PMSE systems. This is because interference-free usage is no longer guaranteed in the presence of today's powerful mobile communication signals [24]. While the allocated frequency range of 823 – 832 MHz under the general assignment under Ruling 09/2011 will be available for a longer period, measurements of compatibility between LTE-800 and PMSE devices conducted by the Sennheiser company in June 2012 indicate that the LTE-800 uplink signal may cause significant interference within this range [25]. This means that the 9 MHz block from 823 MHz to 832 MHz that is available for PMSE usage within the 790 - 862 MHz frequency range cannot in fact be used due to potential LTE interference [24].

While the 863 - 865 MHz frequency range can be used by PMSE devices in accordance with the general assignment, this band is also used by short-range devices for a range of wireless communication applications, meaning that interference-free operation is not guaranteed [24].

Since there is no general frequency assignment in the UHF frequency range below 790 MHz, an individual assignment is always required. In this frequency range, PMSE devices can be operated as secondary users alongside broadcasting. As broadcasting transmitters operate on fixed frequencies, the operating conditions for PMSE devices in this range remain constant and static. Due to the structure of broadcasting networks, TV white spaces (unused channels) occur within the frequency band, which can currently be used by PMSE devices. The 470 – 710 MHz frequency range is used for broadcasting productions and broadcasting-related productions. The frequency range between 710 and 790 MHz is available for all productions that do not fall within the "broadcasting" category. This range of 80 MHz serves as the basis for PMSE usages at most events [24]. For mobile events, the DVB-T channel allocation must be adjusted on-site each time, as simultaneous usage alongside DVB-T is not possible. A guard interval of 600 KHz is required between PMSE systems and DVB-T channels.

3.3 Constraints on the usage of frequencies/channels by PMSE

When several wireless microphones are operated simultaneously, the frequency spacing between two neighbouring microphones must be at least 400 kHz. If a large number of devices are in use at the same location, the required frequency spacing increases, as intermodulation products (IM3, IM5) have to be taken into account. The following table (compiled by Sennheiser) shows how many devices can be operated without intermodulation distortion in various channel frequencies.

The table reveals that a fragmented spectrum, comprising several distributed blocks, can be used effectively as a complete frequency block because several intermodulation-free channels are available if the frequency blocks are widely distributed across the frequency band.

When wireless microphones are used in conjunction with in-ear monitors, the transmitters and receivers are in the same location. As a result, a duplex gap of at least 7 MHz between the frequencies ranges for wireless microphones and in-ear monitors is required in this case.

Bandwidth in MHz	Wireless microphones (standard requirements)	Wireless microphones (demanding requirements)	Mono in-ear monitors (normal requirements)	Stereo in-ear monitors (demanding requirements)
8	10	10	10	7
16	16	15	12	10
24	20	18	14	12
32	28	24	18	13
40	32	26	22	14
48	34	27	24	15
56	36	29	26	17
64	38	30	28	18

Table 3-1: Number of devices that can be operated without intermodulation distortion based on channel bandwidth

3.4 Summary of the spectrum requirements for PMSE systems based on research, plus interviews with system manufacturers and users

- Frequency range allocations for PMSE devices must be valid for longer periods than is currently the case, in order to enable reliable planning by manufacturers and users [27]. System components, such as transmitters, antennae, boosters, splitters, active combiners and receivers, have to be newly developed when the frequency band changes, and system certification is often costly. For users of PMSE devices, band and frequency changes are associated with significant costs if the systems' switching bandwidth is exceeded.
- Following the release of the digital dividend, the 700 MHz frequency range was primarily allocated to PMSE devices. This means that, in the event of a reallocation, users of these devices will be burdened once again with the costs and complexities of another switchover.
- PMSE devices require an interference-free spectrum without interfering signals and man-made noise. As PMSE systems are primarily used at live events, interference with a single transmission path can result in the complete failure of the event. The ISM bands (Industrial, Scientific and Medical), SRD bands (Short Range Devices) and also the duplex gaps between downlink and uplink in the mobile communications

range are unsuitable in most cases due to the potential for interfering signals. Meanwhile, all frequencies below the UHF band, including the VHF band, are still virtually unusable for PMSE devices due to man-made noise.

- The L band (1,452 – 1,477.5 MHz or 1,452 – 1,492 MHz) constitutes an alternative to the spectrum that was lost in the UHF band as a result of the digital dividend, as harmonised usage options in this band are currently under discussion at a European level.
- In the case of mobile PMSE systems, usable frequency ranges (with a general assignment) should be available at a Federal/European level (as is already the case in the 1,800 MHz band) to ensure that a new frequency allocation is not required each time a system is used in a new location.
- Both manufacturers and users of PMSE systems would benefit from the availability of frequencies that are harmonised across Europe.
- If the frequency assignments for the daily requirements of PMSE devices exceed 1 GHz in future, at least 64 MHz will still be required in the UHF band for short-term use for events (e.g. sporting events). For some events, the favourable propagation conditions offered by the UHF band will remain indispensable.
- Different frequencies should be allocated to mobile systems used for touring or events on the one hand and fixed systems on the other because on-site frequency coordination is difficult to achieve. In addition, the use of different frequencies would avoid the possibility of interference from the outset.
- For technical reasons, the PMSE systems that are currently available cannot cover all frequencies in the UHF band. The possible switching bandwidths of analogue systems are 24 MHz, 40 MHz, 90 MHz and 180 MHz, depending on the configuration and quality of the systems involved.
- A duplex gap of at least 7 MHz is required between wireless microphones and in-ear monitoring systems.
- An interleaving of channels for more effective use of frequencies is possible in locations that enable sufficient spatial separation of the channels.
- In urban settings (without line of sight), a guard interval of at least 400 m is required between two PMSE devices sharing the same channel.
- Today, a HF bandwidth of 200 kHz is required for digital and analogue systems with a single audio channel. However, as developments towards greater dynamism and higher quality are also taking place in the audio sector, larger channel bandwidths may be required in future..
- For some large-scale events, the entire UHF spectrum with the exception of the channels occupied by DVB-T (e.g. 320 MHz – 48 MHz (6 x DVB-T) = 272 MHz) is currently used for PMSE devices [26]. In large urban centres, it is entirely possible that more than 96 MHz of the spectrum may be required for PMSE systems on a daily

basis [18]. In most cases, however, the spectrum is only used for the duration of an event, and is then unoccupied until the next usage.

- Frequency blocks sized approximately 24 MHz that are distributed across the frequency range can be used more effectively due to intermodulation and the required duplex gaps. This 24 MHz is also the smallest switching bandwidth of the systems. To ensure interference-free operation of PMSE systems, a guard interval of 600 kHz is required between the channels used for these systems and DVB-T channels.
- At present, digital PMSE systems offer no benefits over analogue technology in terms of spectrum efficiency. Delays and runtime differences due to digital signal processing cannot be tolerated in an event production context. For this reason, only slight signal compressions and relatively ineffective error protection can be used. The amount of spectrum required cannot currently be reduced through digitisation [26] [24].
- A secondary spectrum allocation for PMSE devices only makes sense if the primary usage can be foreseen and if sufficient spectrum remains for the secondary user. It is vital that PMSE systems be able to use the spectrum without interference. Frequency ranges that are actually used by mobile communications can no longer be used by PMSE systems. PMSE systems can only be operated with a secondary assignment in locations where mobile communications frequency ranges remain largely unused for their primary purpose. However, a symbiotic relationship between PMSE and broadcasting is possible first, because broadcasting uses static frequency allocations and second, because a sufficient amount of available frequency always remains for secondary usage within broadcasting networks in any location. Nevertheless, it may still be useful to allocate mobile communications frequencies to PMSE systems as secondary users because experience shows that not all mobile network operators use all frequencies in all areas.
- DVB-T channel 38 (606 – 614 MHz) is not available for PMSE systems because the corresponding frequencies are used in radio astronomy.

The constraints set out above demonstrate that concrete conclusions cannot currently be formulated in relation to the spectrum requirements for PMSE systems. We can summarise the key considerations as follows: The UHF band currently represents the best compromise for PMSE systems. Man-made noise renders the frequency bands below the UHF band largely unusable for productions of any complexity, while the frequencies above 1 GHz are frequently unable to offer the required penetration due to poor propagation conditions. In addition, interference-free operation of PMSE systems can no longer be guaranteed in frequency bands that are available for general usage or that will, in future, be located in direct proximity to the LTE uplink. Due to the network structure, terrestrial broadcasting offers TV white spaces in which PMSE devices can be assigned frequency as a secondary user. Large-scale allocation of the UHF band to LTE would leave no spaces for secondary users, as the same frequencies are used in neighbouring mobile network cells. Spectrum requirements for PMSE systems are stable and lend themselves to planning in the case of fixed equipment. However, the entire UHF range (approx. 270 MHz) may be required for short-term use for large-scale events and large touring productions. The digitisation of PMSE devices offers no benefits in terms of spectrum efficiency. As a result of the digital dividend, many users were required to invest in new PMSE systems or retrofit existing systems, and this was associated with considerable costs in most cases. To allow manufacturers and users of wireless PMSE technology to plan ahead with certainty in the longer term, frequency allocations should also remain valid for longer periods of time.

3.5 Possible scenarios

The following scenarios are based on the possible scenarios for the future use of the UHF band for broadcasting, which we discussed in Chapter 2.

Retain the status quo in the 470-790 MHz frequency band until at least 2020/2025

Good conditions currently exist for PMSE devices in tandem with broadcasting within the UHF band. This scenario offers promising long-term perspectives for users and manufacturers of PMSE devices. In this scenario, all systems that were retrofitted following the digital dividend or that were not affected by the switchover can continue to be used.

Use of the UHF spectrum until 2018 for terrestrial TV broadcasting, with a switchover to DVB-T2 in the period 2016 to 2018, and assignment of the 694 – 790 MHz band to mobile services and PPDR as of 2018

In this scenario, nothing would change for users of PMSE systems in the relevant UHF band until 2016. Between 2016 and 2018, two additional DVB-Tx channels are likely to be required during the DVB-T/DVB-T2 Simulcast phase as part of the switchover to DVB-T2. These two channels would consequently no longer be available for PMSE devices during the transitional phase. An assignment of the 694 – 790 MHz frequency range to mobile services as of 2018 would result in a reduction of just under 38% in the frequency capacities for PMSE systems in the UHF band. At present, 40 channels with a bandwidth of 8 MHz are available for PMSE devices in the 470 MHz – 790 MHz frequency range. However, the channels occupied by DVB-T and channel 38 cannot be used in practice. In the Hanover/Braunschweig area, for example, seven DVB-T channels are in operation, which leaves 32 channels with a channel bandwidth of 8 MHZ (i.e. a total of 256 MHZ) available for use by PMSE devices. If the frequency range were to be reduced to 470 – 694 MHz, only 20 channels with a bandwidth of 8 MHz would remain for PMSE. Furthermore, not all of this remaining total of 160 MHz would be usable in practice because of interference from the LTE uplinks in operation in neighbouring bands. Reducing the available spectrum from 256 MHz to 160 MHz would mean that around 96 MHz of alternative spectrum would have to be found for use by PMSE systems outside of the relevant UHF band. This replacement spectrum would have to be allocated as of 2015 in order to give manufacturers sufficient time to develop new products. The L band could be used to replace part of the spectrum lost within the UHF band, as the L band is the most similar to the UHF in terms of propagation characteristics. Discussions are currently underway towards new usage options for this band that are to be harmonised at European level. PMSE systems are currently assigned spectrum assignment within the 1,452 – 1,477.5 MHz frequency range of the L band as a secondary user. This assignment would need to be extended to 1,452 – 1,492 MHz (or even 1,452 – 1,518 MHz) to compensate for most of the spectrum lost within the UHF band. If that were to happen, 25.5 MHz, or even 40 MHz (66 MHz) following an extension of the assignment, would then be available in the L band, which could be used, for example, for fixed PMSE systems with an individual frequency assignment. However, as a consequence of allocating the L band to PMSE systems, simultaneous use of this band for other radio communication services would only be possible on a very limited basis due to the signal-to-noise ratio required. It would therefore make sense to introduce a primary assignment for PMSE systems and to harmonise this assignment at European level as far as possible. The frequency range from 1,785 MHz to 1,805 MHz and the LTE duplex gap in the 800-MHz band should be retained as a support for systems with a general assignment. However, all of these bands are only viable alternatives provided that the constraints set out above in relation to interfering signals are taken into account.

The options presented here offer a certain degree of planning reliability for both users and manufacturers of PMSE systems. They would give manufacturers of these systems sufficient time to develop systems for new frequency ranges, assuming that a replacement for the lost spectrum is identified as quickly as possible. However, the loss of the 694 – 790 MHz would require many users to retrofit their PMSE systems or invest in new ones, thereby incurring significant costs. Some of the users affected would be users who have already been required to retrofit their systems as a result of the digital dividend.

Shared use of frequencies by terrestrial broadcasters (dynamic broadcasting) and other users (LTE, PMSE etc.)

With collaborative spectrum use, it is particularly important to ensure that channels that are as free as possible of interference and man-made noise continue to be available for PMSE systems. Unwanted emissions from low-cost devices from the same or neighbouring frequency ranges can have a significant impact on the operation of PMSE systems. One benefit of collaborative usage based on a centrally managed dynamic broadcasting concept (see Section 6.2) is that, depending on the size of the event, additional spectrum can be requested for PMSE systems, which can then be obtained from other systems that have a lower priority. This concept could offer a viable option for mobile PMSE applications that are only in operation for the duration of a single, large-scale event. For fixed PMSE systems, many of which are used on a daily basis, dynamic broadcasting would actually represent a poorer solution compared with the static allocation of TV channels that has been the norm to date. Even if dynamic broadcasting is introduced, frequency ranges with a general assignment should still be retained because, if these did not exist, frequency usage for even the smallest of events would have to be managed via centralised databases. The switching bandwidths of PMSE systems may also need to be taken into account in the case of dynamic frequency assignment.

One possible solution for the future is the use of cognitive radio technology for PMSE systems. The C-PMSE research project – “Cognitive Program Making and Special Events” – was launched at the start of April 2011, with the objective of developing solutions based on cognitive methods for improving frequency usage and coexistence for PMSE systems. This project involves nine partners from industry, research institutes and universities, and is funded by the Federal Ministry of Economics and Technology. The German Aerospace Center (DLR) in Cologne is the project management agency for this project. The research underway seeks to design, develop, test and explore a cognitive PMSE system that can be used for collaborative coexistence with other C-PMSE systems, white space devices, broadcasting and mobile services [28].

An end to terrestrial TV broadcasting as of 2020 (approx.)

In this scenario, we can expect the greater part of the spectrum to be assigned to mobile network operators. Secondary usage of the UHF system by PMSE systems in parallel with mobile services or services similar to mobile services (PPDS) would only be possible if mobile networks do not undergo large-scale expansion. Frequency blocks in the UHF band must therefore be assigned to PMSE systems as primary users. This study presents two scenarios, in which two frequency blocks (26 MHz + 16 MHz or 2 x 26 MHz) are assigned to PMSE systems as primary users. The block size has been calculated to take account of intermodulation. The frequency diagrams provided in Chapter 7 of this study show the precise positioning of these blocks within the UHF band. The blocks have been distributed in such a way that the considerations outlined above have been taken into account to the greatest extent possible. The positioning of the PMSE frequencies around TV channel 38, which is used for radio astronomy, was found to be useful here.

Experience shows that mobile network operators do not use the frequencies allocated to them in all areas. Therefore, a secondary assignment for PMSE should be made in all LTE duplex gaps and in the mobile service bands. Provided that no signal is detected in an LTE downlink, it can normally be assumed that the corresponding LTE uplink range is also unused.

As the frequency blocks allocated as a primary assignment do not meet the requirements for PMSE systems in this scenario, additional frequency ranges outside of the UHF band must also be assigned.

The frequency assignments proposed here are intended to provide users and manufacturers of PMSE systems with sufficient time to prepare for the new situation. However, in this scenario, most users will need to modify existing systems or purchase new ones, which is associated with significant costs.

4 Investigations into usage of the UHF spectrum by commercial mobile service broadband applications

This chapter analyses the spectrum requirements of commercial mobile services in Germany. Section 4.1 briefly outlines the initial situation regarding spectrum usage by mobile service in Germany. This is followed by an analysis of total spectrum requirements for commercial mobile services in Germany (Section 4.2). The following section illustrates the principle options available to address the rising capacity requirements of mobile networks. The performance of systems on the market and those undergoing standardisation is analysed in section 4.4. Section 4.5 analyses the potential for coverage in rural areas, depending on the availability of various bandwidths in the UHF band. The chapter is brought to a close with a brief conclusion.

4.1 Spectrum usage by mobile services in Germany: current landscape

Since 1990, frequency usage rights for digital mobile services in Germany have been granted in a total of seven spectrum auctions in blocks of 613 MHz in the 800 MHz, 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz frequency bands. The last auction ran from 12 April to 20 May 2010. During this auction, frequency usage rights amounting to a total of 358.8 MHz were purchased. In addition, 60 MHz of spectrum were also allocated in the 800 MHz band. This was made available for mobile services, as part of the “digital dividend”, by reallocating the terrestrial television spectrum. In Germany, the spectrum is used by four mobile operators, which operate the networks according to the 3GPP (Third-Generation Partnership Project) standards: GSM, UMTS and LTE. GSM is available extensively throughout Germany in all four networks. In 2012, by the end of the third quarter, these networks had handled 114.2 million mobile connections [31].

Following the decision made at the World Radiocommunication Conference 2012 (WRC 2012) about the agenda for WRC 2015, two items on the agenda (items 1.1 and 1.2) about the allocation of additional frequencies for mobile services were identified. Agenda item 1.1 resolves to consider additional frequency allocations to mobile services on a primary basis and identification of additional frequency bands for International Mobile Telecommunications (IMT) to facilitate the development of terrestrial mobile broadband applications. Agenda item 1.2 examines the use of the frequency band 694 to 790 MHz by mobile services in region 1 (Europe and Africa). The initiative for allocating this frequency band was a response to demand by African and Arab countries, where the 800 MHz band is not available for mobile services [29]. The relevant authorities intend to alleviate this shortage at 800 MHz by introducing IMT applications in the 700 MHz band, which is not yet used for digital radio applications in the respective countries. In Europe, the 800 MHz band was released for mobile services shortly after WRC 2007. The release was accompanied by relevant regulatory measures designed to guarantee interference-free operation of other services. These include, for example, steps taken to handle interference in broadcasting services at frequencies below 790 MHz, measures to protect cable television at 800 MHz and the redistribution of spectrum for PMSE applications from the 800 MHz band to other bands.

Frequencies in the UHF band are highly attractive to mobile network operators. It is assumed that the allocation of additional frequencies below 1 GHz will mean that network operators will require significantly fewer cells for nationwide coverage than they need with higher frequencies [30]. For example, it is estimated that a third-generation standard mobile radio network at 700 MHz requires approximately 30% of the cells needed at 2100 MHz to provide the same coverage. The spectrum in the 700 MHz band allows for efficient reuse of sites that are used for GSM 900, making it less expensive to establish a network.

4.2 Current discussions on traffic forecasts and spectrum requirements

Outlook and opinions

This section addresses the frequency requirements for mobile services over the next five to ten years. To this end, we will analyse forecasts for mobile data traffic from a variety of publicly available sources. According to the statistics published in the Cisco Visual Networking Index [32], global mobile data traffic increased by around 522% between 2008 and 2010. In 2010, total data traffic reached roughly 237 petabytes per month. The huge growth rates are the result of technological development and the introduction of new services. The average connection speed in mobile networks increased from 101 kilobits per second (kbps) in 2009 to 215 kbps in 2010 and then to 315 kbps in 2011. In the wake of the introduction of fourth-generation (4G) systems by 2016, the average mobile network speed in 2016 will exceed 2.9 megabits per second (Mbps) [33]. Overall, these developments will significantly enhance the possible applications of mobile networks. Meanwhile, the proliferation of new services, such as the use of mobile apps for games, news, social networks, maps and the introduction of new device generations, e.g. smart phones, tablets and dongles, have all contributed to the increase in mobile Internet usage. Video-based services like YouTube and Flash have been a significant factor in the growth of global mobile data traffic. The various forecasts are discussed in the following section.

Cisco study

According to Cisco's data traffic forecast [33], global mobile data traffic grew by 133% in 2011 alone. The trend shows that global mobile data traffic will increase to approximately 6.9 exabyte (EB) per month in 2015 and 10.8 EB per month by 2016. The introduction of diverse mobile devices on the market has been identified as one of the key reasons for the growth of mobile data traffic. Almost half of all mobile data traffic in 2016 will be generated by smart phones (48.3%), exceeding total mobile data traffic on laptops and netbooks (24.2%). Moreover, average traffic per device is expected to increase by a factor of 3.3 between 2011 and 2016. In the case of smart phones and tablets, it is estimated that average data traffic will increase by a factor of 17.2 and 8.2 respectively.

Due to the prevalence of mobile video applications and the fact that mobile video content has much higher bit rates than other mobile content types, it is assumed that mobile video traffic will account for 70% of all mobile data traffic, at a rate of 10.8 EB crossing mobile networks per month, in 2016. Figure 4-1Figure 4-1 illustrates the forecast for global mobile data traffic between 2011 and 2016.

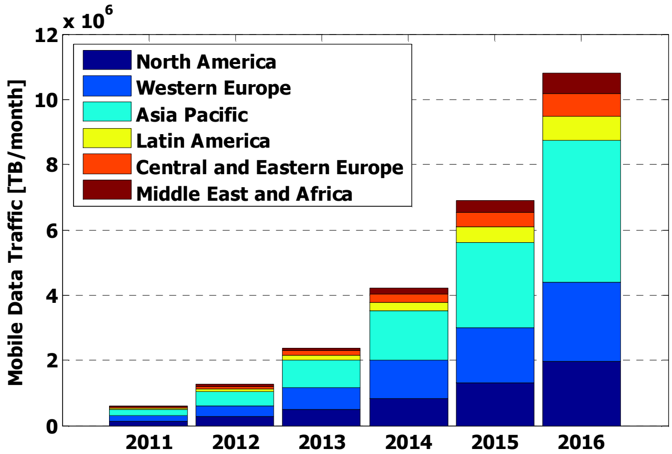

Figure 4-1: Cisco's global mobile data traffic forecast [33].

UMTS Forum report: Mobile traffic forecast [34]

The mobile data traffic forecasts for 2010-2020 [34] published by the UMTS Forum identify the most important trends and drivers contributing to the growth of mobile data traffic. After mobile voice traffic was surpassed by mobile data traffic in 2009, it is expected that mobile data traffic will dominate further by 2020. It is estimated that total global mobile data traffic will grow to more than 127 EB (Figure 4-2Figure 4-2) in the year 2020. That is 33 times more than the volume recorded in 2010. Compared to the estimated traffic in Cisco's forecast [32], the estimated global mobile data traffic is somewhat lower at 4 EB per month in 2015. The expected rollout of new mobile devices like tablets, dongles and smart phones will act as the driver for growth. In addition, the planned deployment of LTE and LTE-Advanced standards for 2015, the use of small cells and femtocells to increase network capacity and, consequently, total mobile data traffic will also increase considerably.

Figure 4-3 illustrates the estimated monthly data traffic per device in Western European countries where most mobile data traffic originates from dongles that are connected to laptops or netbooks. However, this projection contradicts the above-mentioned forecasts, which assume that smart phones will dominate.

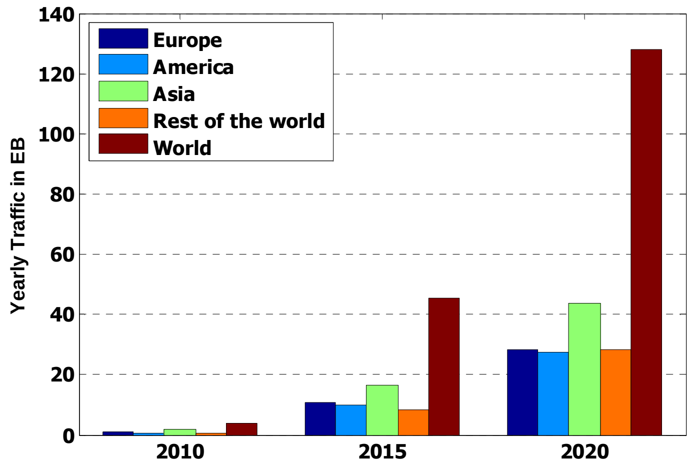

Figure 4-2: Total mobile data traffic (EB per year) [34].

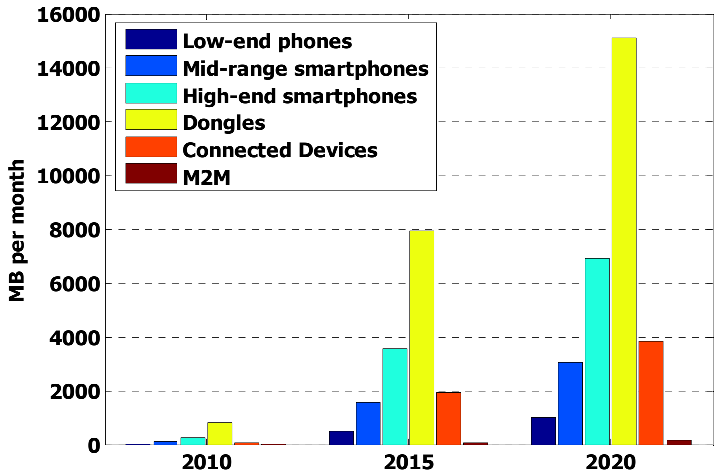

Figure 4-3: Monthly mobile data traffic per device (Western European countries) [34].

Analysys Mason

Analysys Mason's forecast on mobile data traffic is considered the most conservative forecast of all the studies published. Although the rollout of diversified mobile devices could increase general demand for mobile data traffic, it is assumed that most traffic generated by smart phones and tablets used inside buildings will be offloaded onto WLAN or over a fixed network and not over cellular radio networks, as forecast by many other studies [35]. A 3.6-fold increase in mobile data traffic in Western Europe is predicted between 2012 and 2017. This corresponds to the lowest growth rate in all regions. Global mobile data traffic will increase by a factor of 5.5 between 2012 and 2017. Figure 4-4 shows Analysys Mason's growth multiple for mobile data traffic between 2012 and 2017.

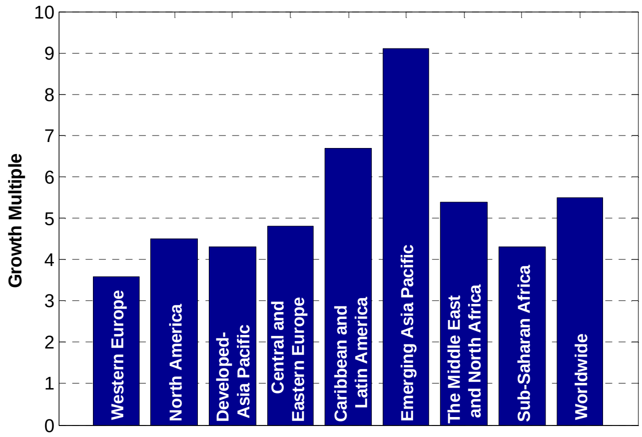

Figure 4-4: The growth multiple for mobile data traffic between 2012 and 2017 in various regions according to Analysys Mason [35].

Lüders/Sörries [36]

Another study that focuses on spectrum requirements for future LTE networks was published by the authors Lüders and Sörries in 2012 [36]. In 2010, mobile data traffic in Germany amounted to 65 MB per month per inhabitant. The study assumes data traffic of approximately 2 GB per month per inhabitant in 2015 and a further increase to 6 GB per month per inhabitant in 2020.

The authors also studied the effects of various frequency bands on total spectrum requirements. They compared the performance of mobile communications systems using various simulations at 800, 2600 and 3500 MHz for urban, suburban and rural scenarios. In areas of urban density (with distances of up to 1 km between base stations) and areas of suburban density (with distances of up to 4 km between base stations), they found no significant differences with regard to spectral capacity between the frequencies at 800, 2600 and 3500 MHz. The spectral capacity is determined to be 5 Mbps/MHz/site. Due to lower propagation losses at lower frequencies, the spectrum below 1 GHz acts as an important resource for providing coverage for mobile services in rural areas. However, the study also points out that a wavelength of 12 cm at 2600 MHz is far more efficient for implementing MIMO (Multiple-Input-Multiple-Output) technology than a wavelength of approximately 40 cm at 700 or 800 MHz. For this reason, the authors ask whether allocation of the additional spectrum at 694 to 790 MHz for mobile services during the next WRC 2015 will cater for the rapid growth with the mobile communications industry.

The study estimates the downlink spectrum requirement for various scenarios. It concludes that the spectrum currently allocated for mobile operators will be sufficient for a period of four to five years. After that, 50 MHz of additional spectrum will be needed to absorb the growth in downlink traffic. This additional requirement can be reduced further by improving spectral efficiency in the LTE-Advanced systems.

ITU-R M.2243 [37]

One of the areas covered in Report ITU-R M.2243 is the market analysis conducted between 2003 and 2005 on which Report ITU-R M.2072 [38] is based. The report is based on internal and external studies from various sources and conveys an insight into the market-based parameters in different regions. This report also presents total mobile data traffic generated between 2008 and 2010 from various sources. Figure 4-5 shows the total mobile broadband traffic per month for CEPT (European Conference of Postal and Telecommunications Administrations) member states in 2010 in 2010. Figure 4-6 shows the corresponding total daily traffic per subscription. Although the volume of monthly mobile data traffic in Germany is the highest among all CEPT countries, average daily traffic only amounts to 4.8 MB per subscription. Compared to daily mobile data traffic in Sweden and Finland, the total daily mobile data traffic per subscription in Germany is considered low among European countries. Figure 4-5 and Figure 4-6 show large fluctuations in mobile data traffic between the CEPT countries, which are also largely affected by data traffic tariffs and market penetration of the network.

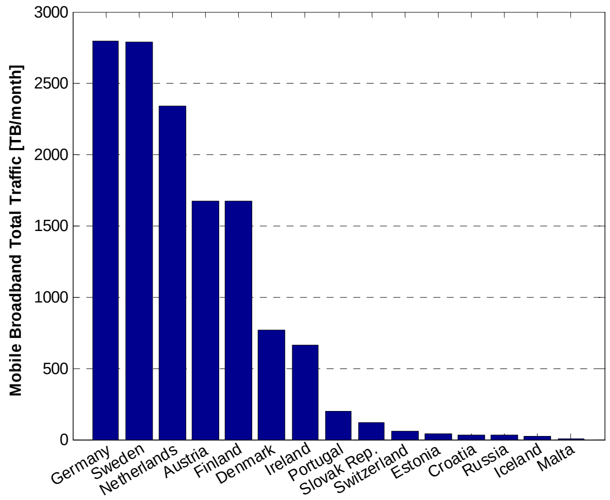

Figure 4-5: Broadband mobile data traffic per month in CEPT countries in 2010 [34].

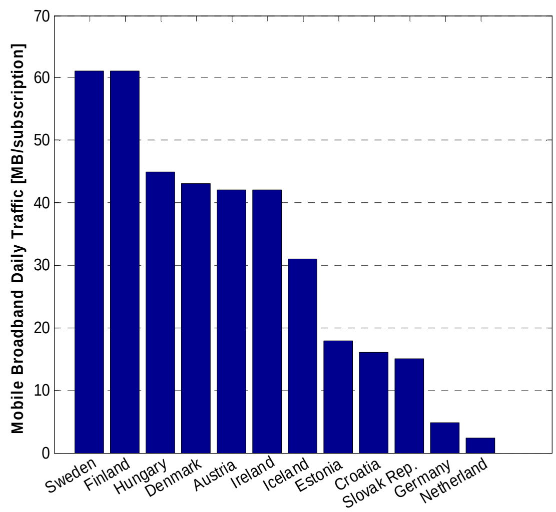

Figure 4-6: Daily broadband mobile data traffic per subscription in 2010 [34].

Speculator [39]

The information in Report ITU-R M.2072 is used as the raw data for the spectrum requirements calculation tool (known by its abbreviation Speculator), which was developed as part of the WINNER project (IST-4-027.756 WINNER II) [39].Speculator is based on the ITU-R M.1768 [40] spectrum calculation methodology and is also described in detail in a book written by Takagi and Walke [41]. The spectrum requirements derived using this methodology were documented in Report ITU-R M.2078 [42]. Twenty service categories were used to calculate spectrum requirements. These consisted of four different classes of traffic (conversational, streaming, interactive, background) and five types of service (super-high, high, medium and low rate multimedia data or data with very low data rates, e.g. voice and SMS) each of which were studied in dense urban, suburban and rural scenarios. In addition, four mobility classes with varying usage rates for unicast and multicast traffic were examined.

Based on the market statistics in Report ITU-R M. 2072, spectrum requirements for various radio access technologies (RAT) for 2010, 2015 and 2020 were presented. For this purpose, the radio access technologies were divided into two classes (RATG 1[1] and RATG 2[2]). Since the distribution of traffic on the European market can vary considerably depending on market penetration, the forecast was based on two different assumptions about the market. The higher market share corresponds to 25% of the maximum number of participants per km^2 documented in ITU-R M. 2072, while the lower market share corresponds to 5%.

Parameter	Macrocell	Microcell	Picocell	Hotspot
Application data rate (Mbps)	20	40	40	-
Maximum speed (km/h)	250	50	4	-
Guard bands between network operators (MHz)	0	0	0	-
Minimum deployment per network operator per radio environment (MHz)	40	40	40	-
Multicast transmission mode	Yes	Yes	Yes	-
No. of overlapping network deployments	1	1	1	-

Table 4-1: Radio parameters for RATG 1.

Parameter	Macrocell	Microcell	Picocell	Hotspot
Application data rate (Mbps)	50	100	1000	1000
Maximum speed (km/h)	250	50	4	4
Guard bands between network operators (MHz)	0	0	0	0
Minimum deployment per network operator per radio environment	20	20	120	120

[1] Pre-IMT systems, IMT-2000 and its enhancements: GSM, UMTS and the other 3G systems
[2] IMT-Advanced: LTE, LTE-Advanced, WiMAX II and the other 4G systems.

(MHz)				
Multicast transmission mode	Yes	Yes	Yes	Yes
No. of overlapping network deployments	1	1	1	1

Table 4-2: Radio parameters for RATG 2.

Years	Mode	2010	2015	2020
Macrocell	Unicast	1	1,5	2
	Multicast	0,5	0,75	1
Microcell	Unicast	2	3	4
	Multicast	1	1,5	2
Picocell	Unicast	2	3	4
	Multicast	1	1,5	2
Hotspot	Unicast	-	-	-
	Multicast	-	-	-

Table 4-3: Spectral efficiency for RATG 1 in bps/Hz/cell.

Years	Mode	2010	2015	2020
Macrocell	Unicast	2	4,25	4,5
	Multicast	1	2,125	2,25
Microcell	Unicast	2,5	5,5	6
	Multicast	1,25	2,75	3
Picocell	Unicast	3	7	7,5
	Multicast	1,5	3,5	3,75
Hotspot	Unicast	5	8,25	9
	Multicast	2,5	4,125	4,5

Table 4-4: Spectral efficiency for RATG 2 in bps/Hz/cell.

The calculation of spectrum requirements for RATG 1 and RATG 2 is based on the radio parameters, which are summarised in Table 4-1 and 4-2. Four radio environments – macrocells, microcells, picocells and hotspots – are taken into consideration. It is assumed that each of the radio environments is characterised by specific data rates and specific user behaviour. It is further assumed that hotspots do not exist in RATG 1.

The spectral efficiencies for RATG 1 and RATG 2 in 2010, 2015 and 2020 for unicast and multicast transmission mode are illustrated in Table 4-3 and 4-4. The spectral efficiency for multicasting is 50% of the spectral efficiency for unicast. This is because, in multicast operation, the radio resources are deployed in accordance with the users with the weakest reception quality [41]. It is understood that the spectral efficiency of RATG 1 and RATG 2 will improve over time, especially if the existing radio systems, e.g. GSM, are gradually replaced with more efficient systems. It is also expected that the enhancement of MIMO in LTE-Advanced will further improve the overall spectral efficiency of RATG 2.

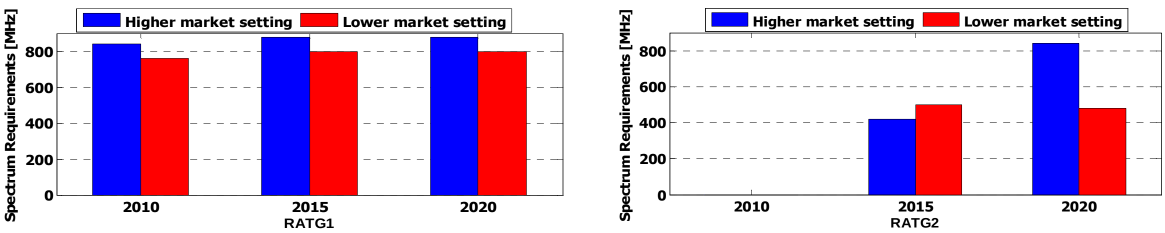

Figure 4-7: Predicted spectrum requirements for RATG 1 and RATG 2 [42].

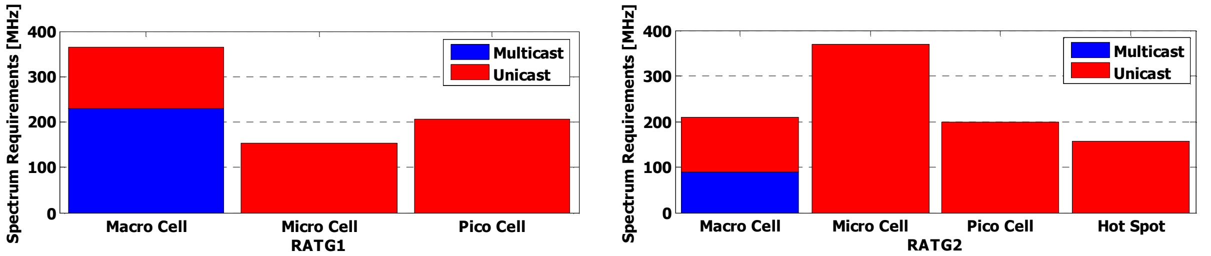

Figure 4-8: Predicted spectrum requirements for RATG 1 and RATG 2 in 2020 for dense urban areas by cell type [42].

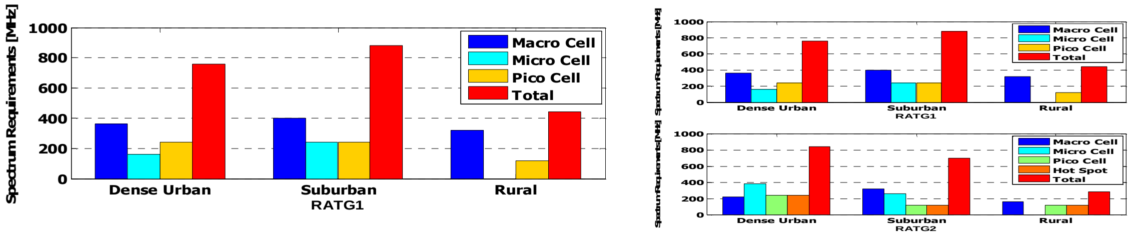

Figure 4-9: Predicted spectrum requirements for RATG 1 and RATG 2 by environment and cell type in 2020 [42].

Figure 4-7 illustrates the predicted spectrum requirements for RATG 1 and RATG 2 for a lower and higher market share respectively. In the case of the lower market share, the estimated total spectrum requirements for RATG 1 in 2010, 2015 and 2020 amount to 760 MHz, 800 MHz and 800 MHz. For IMT-Advanced systems and systems classified in the RATG 2 group, the total spectrum requirements for 2015 and 2020 are expected to be 500 MHz and 480 MHz respectively. This leads to total spectrum requirements in the case of the lower market share of 760 MHz for 2010, 1300 MHz for 2015 and 1280 MHz for 2020 for all RATG 1 and RATG 2 systems [41]. In the case of the higher market share, the total spectrum requirements for 2010, 2015 and 2020 are predicted to be 840 MHz, 1300 MHz and 1720 MHz respectively. To sum up, the total spectrum requirements extrapolated for RATG 1 and RATG 2 in 2020 will be between 1280 and 1720 MHz. This figure includes the frequency ranges that are already used for RATG 1, such as GSM and UMTS[42].

Figure 4-8 illustrates the spectrum requirements for RATG 1 and RATG 2 for dense urban areas in 2020. Figure 4-9 illustrates the spectrum requirements for environments and cell types for RATG 1 and RATG 2 in 2020. Please note that microcells are not used in rural areas for RATG 1. The spectrum requirements for RATG 1 are dominated by demand in suburban areas, while spectrum requirements for RATG 2 are dominated by demand in urban areas. In the case of RATG 1, macrocells have the greatest spectrum requirements, whereas the highest spectrum requirement for RATG 2 comes from micro cells. In the case of RATG 2, the allocated frequencies are reused, as picocells and hotspots do not overlap geographically. The total spectrum requirements for RATG 2 are derived from totalling the macrocells and microcells and the maximum number of picocells and hotspots.

Comparing the forecasts

This section describes the comparison between different data traffic forecasts for the next five to ten years. Figure 4-10 shows the forecasts in Report ITU-T M.2072, which are used as raw data for the Speculator calculations. The result consists of a series of data traffic forecasts (blue, see Figure 4-10), which were derived from different scenarios and radio environments. Compared to the actual mobile data traffic specified by Cisco [32] for the period between 2007 and 2010 (yellow line in Figure 4-10), the data traffic forecast from the ITU-R M. 2072 report is more pessimistic and much lower than the actual traffic data. An extended Cisco forecast estimates that the traffic in 2015 will be more than five times greater than that forecast in Report ITU-R M. 2072. Consequently, the spectrum requirement of 1280 MHz calculated by Speculator can represent only a minimum requirement.

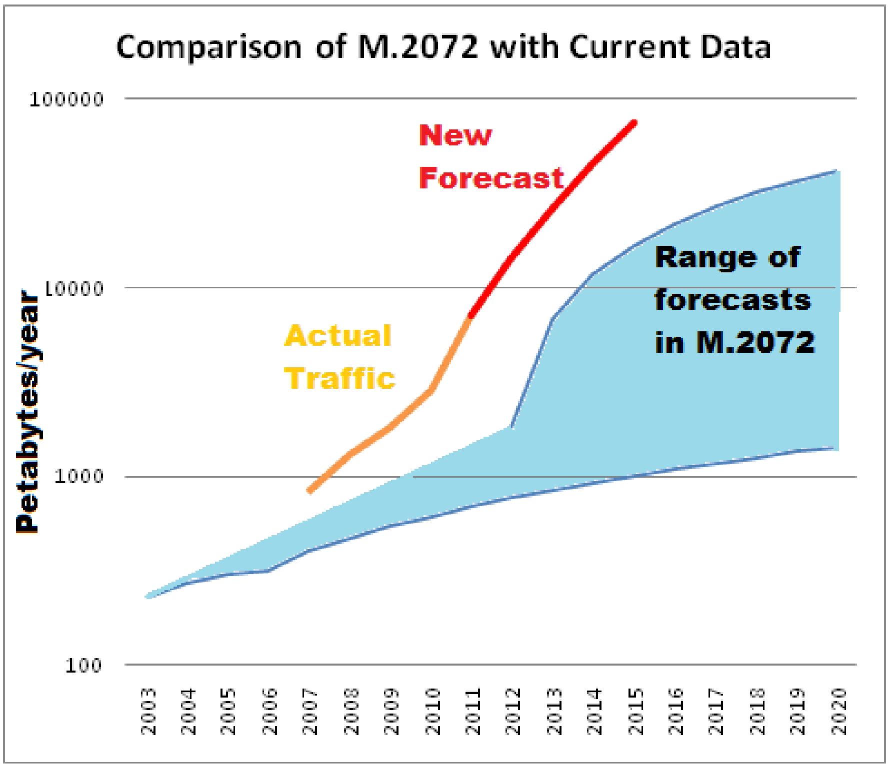

Figure 4-10: Comparison between the forecast provided by ITU-R M.2072 (blue curves) and the current data traffic (yellow curve) or Cisco's extended forecast [37] (red curve).

For further comparisons, Figure 4-11 shows the forecast for global mobile data traffic from 2011 to 2015 from a variety of sources. The Cisco and Alcatel-Lucent forecasts show that total data traffic will increase rapidly over the coming four to five years, with mobile data traffic in excess of 6.5 EB per month. On the other hand, the forecast issued by the UMTS Forum [34] predicts that the growth of mobile data traffic will advance at a slower rate. Ericsson's forecast is similar and comparable to the UMTS Forum's forecast. The most conservative mobile data traffic forecast was issued by Analysys Mason. If we average out the forecasts of all available global mobile data traffic sources, Ericsson's forecast comes closest to the average.

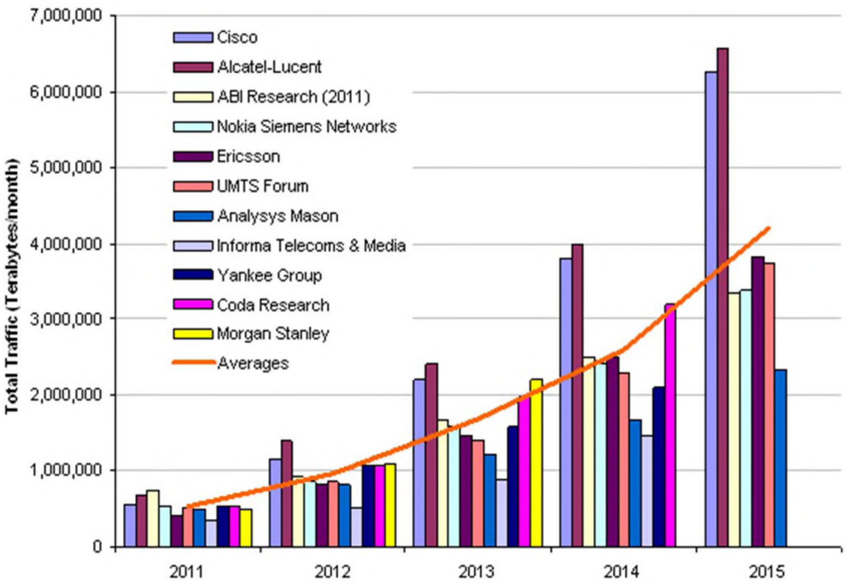

Figure 4-11: Predicted global mobile data traffic between 2011 and 2015 [37]

4.3 Options available to handle rising capacity requirements

The following conclusions can be drawn from the analysis of the traffic forecasts and the spectrum requirements predicted:

- While the various traffic forecasts differ, they all agree that mobile data traffic will increase sharply by 2020.
- In 2005, the traffic forecast for 2005 to 2020 was used to determine total spectrum requirements of 1280 to 1720 MHz for 2020. In 2011, the actual volume of data traffic exceeded this forecast figure by a factor of 5.

The main options for meeting increased demand for capacity caused by the sharp growth in traffic are below:

1. *Densification of the network*: This option would entail additional investment in the network infrastructure.
2. *Offloading by means of WLAN access points or the use of femtocells*: With these options, the data traffic generated by the use of mobile end devices is offloaded via WLAN or femtocells, which are connected over the fixed network. However, these two options can only be deployed where there is a suitable fixed network connection and are to be considered for covering capacity requirements in urban areas, in particular. . Alternatively, the expansion of regional WLAN networks is also under consideration, for example in the United Kingdom (see the Ofcom plans [68] for using TV white spaces). With regard to the use of femtocells, the Smallcell Forum predicts that 90% of all base stations will be femtocells by 2016 [56]. In terms of future offload options via WLAN, it should be taken into consideration that the 802.11ad standard [57], which was finalised in 2012 and operates at 60 GHz, provides a globally harmonised

spectrum of 7 GHz. However, the areas of application are not suitable for all radio environments due to the high propagation losses at 60 GHz.

3. *Increase in spectral efficiency*: Advances in mobile radio technology have led to the development of transmission methods with a higher spectral efficiency. For an overview of the spectral efficiency of different variants and generations of mobile communications systems, see Table 4-5. An increase in capacity can therefore also be achieved by gradually replacing second- and third-generation mobile communications systems, e.g. GSM and UMTS, with fourth-generation systems, such as LTE-Advanced. The use of GSM, at least, is expected to decline significantly in the period between 2020 and 2025 [58].
4. *Provision of additional spectrum*: If this option is to be used, additional spectrum, previously used for other radio services, must be identified and redesignated. If we assume the above-mentioned prediction regarding total spectrum requirements of 1280 to 1720 MHz and an already identified spectrum of 1013 MHz [43, 44] for commercial mobile telephony, this results in an additional spectrum requirement of approximately 270 to 700 MHz.
5. *Tariffs*: Impose a tariff on data traffic in a way that curtails the predicted growth.
6. *Innovative technology for broadcast applications*: Introduce the innovative approaches described in Chapter 6, in particular the implementation of point-to-multipoint solutions in mobile networks, such as eMBMS, tower overlay over cellular networks or dynamic broadcasting.
7. *Introduction of a digital dividend in mobile communications*: The digital dividend in terrestrial TV transmission arose from the fact that inefficient analogue television was replaced by the much more efficient DVB-T system. A comparable digital dividend could be expected if the GSM system was replaced by IMT advanced systems.
8. *Fixed network infrastructures*: Expand fixed network infrastructures in rural regions, so that data traffic in these areas could be offloaded from the mobile networks to the fixed networks.

4.4 Performance of mobile communications systems

This section describes the performance of modern mobile communications systems with the aim of providing a clearer understanding of the spectrum requirements for establishing such systems. Table 4-5 shows the theoretical maximum spectral efficiency of various mobile communications systems compared to the values determined by simulations carried out in the 3GPP or in field trials, or the values that have been assumed by the US American regulatory authority, the FCC. In general, spectral efficiency of less than 0.2 bps/Hz is theoretically possible for second-generation systems such as GSM and EDGE. In third-generation systems, the spectral efficiency increases significantly to 0.4 bps/Hz for UMTS, 1.44 bps/Hz for HSPA Rel. 5, 2.88 bps/Hz for HSPA Rel. 6 and up to 4.2 bps/Hz for HSPA+ Rel. 7. A modern mobile radio communications system like LTE provides a maximum, theoretical spectral efficiency of approximately 5 bps/Hz. Comparing the spectral efficiency determined using the 3GPP simulation with the maximum theoretical spectral efficiency results in a value that is lower by a factor of between 2 and 8 than expected in theory. On the other hand, the values obtained from the 3GPP simulation are consistent with values obtained in field trials for LTE with MIMO [48, 55]. According to the 3GPP simulation, the average spectral efficiency for mobile communications systems in RATG 1 ranges from 0 to 1 bps/Hz/cell. In the case of RATG 2, the average spectral efficiency of the 3GPP simulation ranges from 1 to 5.5 bps/Hz/cell. These values correspond well to the assumptions made in [39], which are presented in tables 4-3 and 4-4 for 2010.

Table 4-5 provides a guide for assessing the results of the study described in Section 4.5regarding the potential of allocating additional spectrum for commercial mobile services.

Technologies	Maximum spectral efficiency (bps/Hz) 3GPP Specification	Spectral efficiency (bps/Hz/cell) 3GPP Simulation	Spectral efficiency (bps/Hz/cell) FCC Assumptions	Spectral efficiency (bps/Hz/cell) Field trials
GSM	0.04 [49] [3]	-	-	-
GPRS	0.05 [49,50] [4]	-	0.03 [45]	-
EDGE	0.2 [49, 50][5]	-	0.09 [45]	-
UMTS	0.4 [53]	0.19 [46]	0.16-0.24 [45]	-
HSPA (Rel. 5)	1.44 [51-53]	0.45-0.50 [46]	0.48 [45]	-
HSPA (Rel. 6)	2.88 [51-53]	0.68-0.76 [46]	0.72 [45]	0.40 [54]
HSPA+ (Rel. 7)	4.2 [51-53]	0.68-1.13 [46]	1.08-1.29 [45]	-
LTE (Rel. 8)	5	-	1.36-1.5 [45]	-
LTE (Rel. 8) 1x2 MIMO	-	1.12 [46]	-	-
LTE (Rel. 8) 2x2 MIMO	8.64 [53]	1.32 [46]	-	1.57-2.10 [48]
Technologies	**Maximum spectral efficiency (bps/Hz) 3GPP Specification**	**Spectral efficiency (bps/Hz/cell) 3GPP Simulation**	**Spectral efficiency (bps/Hz/cell) FCC Assumptions**	**Spectral efficiency (bps/Hz/cell) Field trials**
LTE (Rel. 8) 4x2 MIMO	-	-	-	-
LTE (Rel. 8) 4x4 MIMO	16.3 [47]	2.08 [46]	-	Doubled from 2x2 MIMO [55]
LTE (Rel. 10) 2x2 MIMO	-	2.09 [46]	-	-
LTE (Rel. 10) 4x2 MIMO	-	2.60 [46]	-	-
LTE (Rel. 10) 8x4 MIMO	-	5.44 [46]	-	-
LTE (Rel. 10) 8x8 MIMO	30.6 [47]	-	-	-

Table 4-5: Spectral efficiency of various mobile communications systems

[3] Assuming a frequency reuse factor of 12
[4] Assuming a frequency reuse factor of 12
[5] Assuming a frequency reuse factor of 12

4.5 Potential use of the UHF spectrum for commercial mobile radio communication

Potentially available spectrum in the UHF band is of interest for commercial mobile communications for two reasons. First, the UHF spectrum can help to cover total spectrum requirements; second, spectrum in the UHF band offers benefits for extensive coverage, particularly in rural areas, due to favourable propagation conditions. No specific study on spectrum requirements below 1 GHz was available at the time this expert report was written. However, the Mobile Media 2020 discussion paper, published by the Federal Ministry of Economics and Technology [64], refers to the Federal Government's objective to ensure that every citizen has a broadband connection of 50 Mbps and explicitly states that cellular mobile communications technologies will also be used to achieve this objective. Bitkom [65] and Deutsche Telekom [66] both address this issue in their responses to the discussion paper and point out that spectrum in the UHF band can help to achieve the objectives. In its response, E-Plus [67] is critical in this regard and considers a broadband speed of 50 Mbps to be unrealistic.

To gain an insight into which data rates and how much spectrum can be achieved in the UHF band, the authors of this expert report carried out their own simulations for a system in accordance with LTE Rel. 8 (without assuming the use of MIMO). The simulation assumptions are based mainly on the corresponding 3GPP documents [59, 60] and are as follows:

- 19 base stations with sectorisation into three sectors in a hexagonal grid
- Variations in the distances between base stations of between 500 m and 10 km
- Calculation of path loss using the Okumura Hata model, plus an additional penetration loss of 20 dB (TR 36.814 – Table A.2.1.1-1)
- Standard deviation for lognormal fading: 8 dB
- Incorporation of the antenna diagrams according to 3GPP TR 36.814 V9.0.0 [60]
- Transmission power of base station: 46 dBm
- Cable loss: 3 dB
- A worst-case estimate is assumed for calculating interference, i.e. all resource blocks in neighbouring cells are in use.
- Assumption of round-robin scheduling
- Assumption of 20 simultaneous users per km^2 (to put this in context: in Germany, areas with 150 people or fewer per km^2 are considered to be rural areas [61], while an average of two people live in a household according to the Federal Statistical Office)
- A total of 1,000 snapshots was generated for each scenario in which the participants were randomly distributed with a rectangular probability distribution function in the cell area.

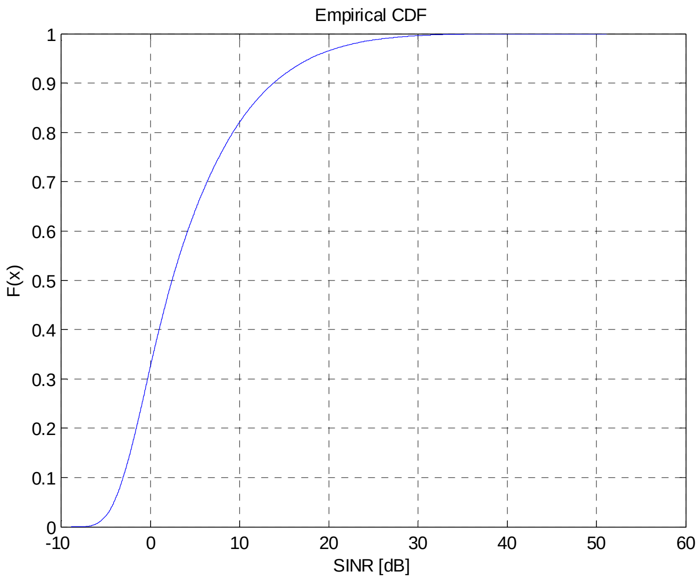

Figure 4-12: Cumulative probability density of the SINR determined from the simulation (two examples for explanation purposes: with a probability of 82%, the SINR value is less than 10 dB, in 65% of cases the SINR value is less than 5 dB)

Figure 4-12 shows the distribution of the SINR (Signal-to-Noise-and-Interference-Ratio) determined in the simulation. The representation in Figure 4-12 corresponds very closely to the relevant representations in [36]. The correlation between SINR and spectral efficiency in the curve depicted in Figure 4-13 was determined from a linklevel simulation using the simulator in [63]. In addition to the noise, fading effects were also taken into account. This curve therefore differs from the curve used in [36]. For the curves depicted in Figure 4-12 and 4-13, an average SINR of 4.4 dB and an average spectral efficiency of 0.78 bps/Hz were determined. This value is slightly lower than the value in Table 4-5 determined using LTE Rel. 8 with 1x2 MIMO.

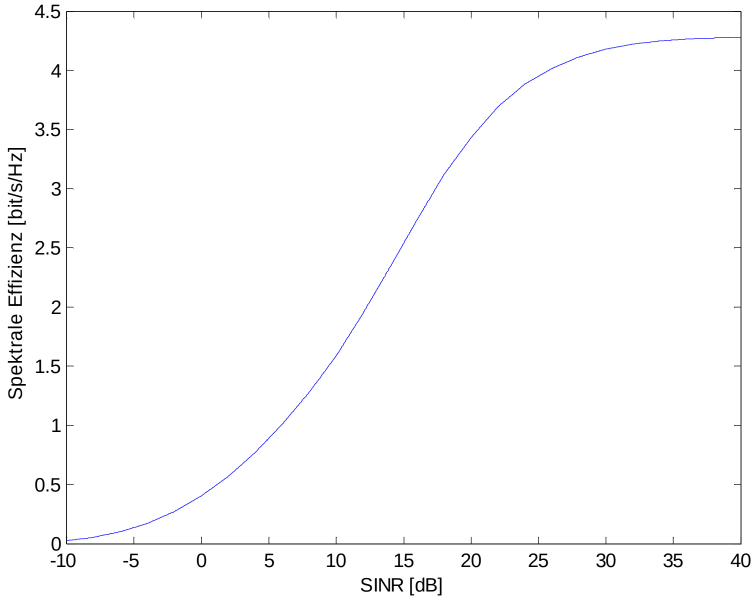

Figure 4-13: Correlation between spectral efficiency and SINR, determined from an independent link-level simulation for LTE Rel. 8.

Figure 4-14 shows the data rates that can be achieved per user for various bandwidths in the downlink and various base station distances. The selected bandwidths are based on the available bandwidths, corresponding to the band plans presented in Chapter 7. However, it should be noted that the carrier aggregation available as of LTE Release 10 provides for an aggregation of channels only up to a total bandwidth of 100 MHz. It is becoming clear that data rates of 50 Mbps are only possible if there is a distance of 500 m between base stations and available bandwidth of 140 MHz. With a bandwidth of 60 MHz and a distance of 2.5 km between base stations, 50% of users have a data rate of only 1 Mbps. However, it should be noted that the results scale according to the number of participants and the spectral efficiency. If we assume a 2.5-fold increase in spectral efficiency, which can be achieved by using 2*2 MIMO for example (provided there are feasible antenna sizes for the MIMO antenna in the end device, see above) and if we assume just one active user per km^2 at a given moment, this user would have a 50% probability of achieving 50 Mbps at 65 MHz. In the simulation, omnidirectional reception was assumed for the mobile station. By increasing the SINR by 10 dB, which can be achieved by using directional antennae for the stationary reception for example, the average spectral efficiency increases to 3.36 bps/Hz. The results for a base station distance of 2.5 km are shown in Figure 4-15.

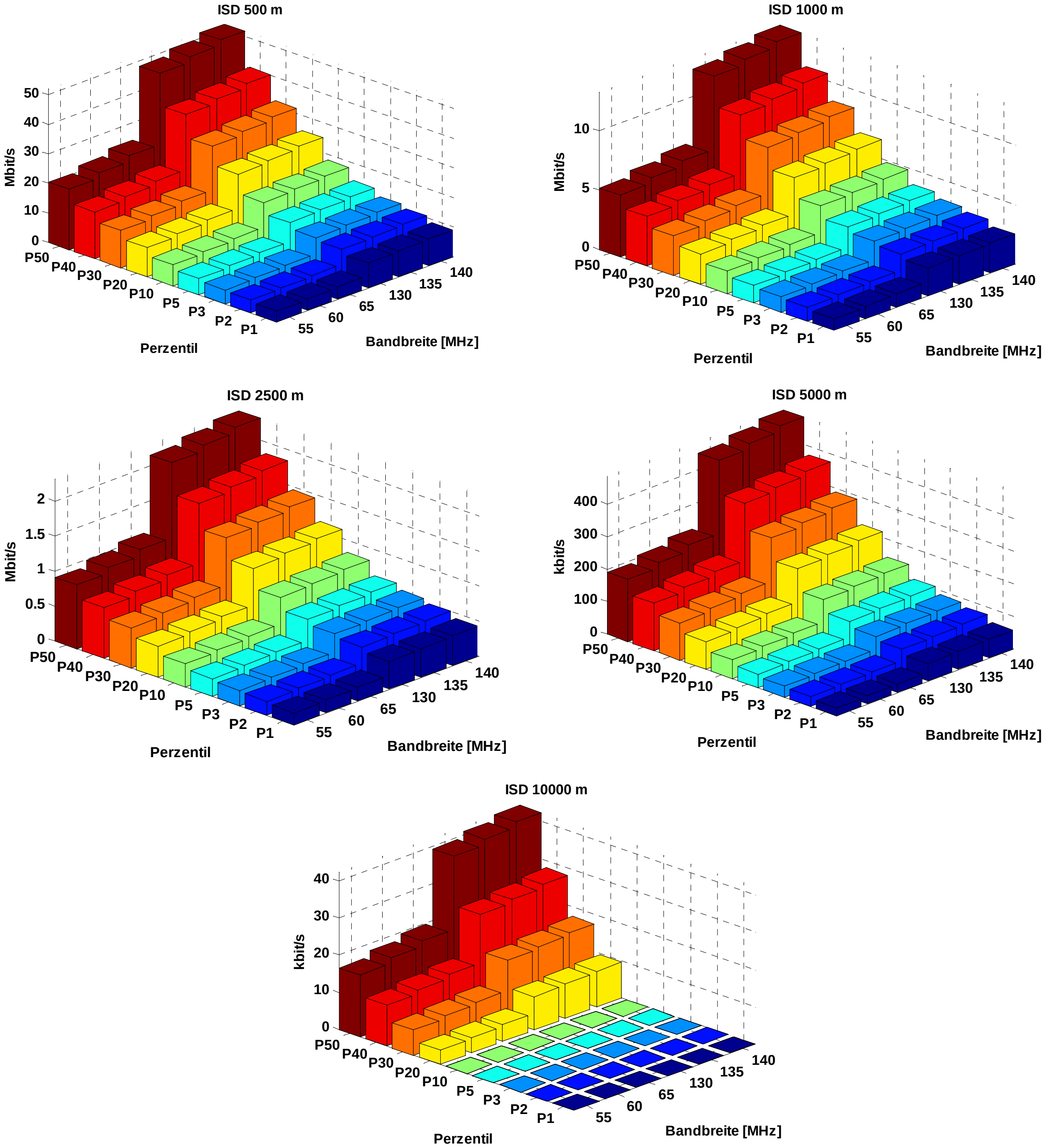

Figure 4-14: Percentiles of achievable data rates per user for various bandwidths in the downlink and base station distances (ISD: Inter Site Distance)

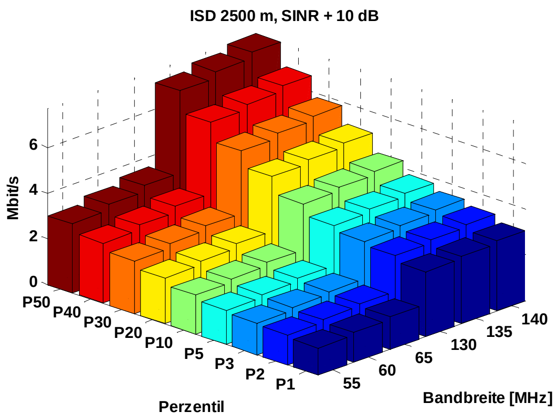

Figure 4-15: Percentiles of achievable data rates per user for various bandwidths in the downlink, with a base station distance of 2.5 km and an SINR value that has been improved by 10 dB

The results achieved in this section clearly show that to achieve the broadband access required by the Federal Government with data rates of 50 Mbps based on LTE-A in rural areas for the downlink, a spectrum tranche of the order of 50 to 100 MHz in the UHF band must be made available. Furthermore, due to the required distances of less than 10 km between base stations, huge investment in the infrastructure is needed to even come close to reaching this goal.

4.6 In summary

It makes sense to allocate additional spectrum in the UHF band for commercial mobile services: first, in terms of satisfying future total spectrum requirements of at least 1280 MHz; second, in terms of the potential to provide coverage for rural areas. Since the spectrum required in the UHF band is heavily dependent on the assumptions regarding traffic, base station density and the spectral efficiency of the technologies used, it is difficult to ascertain an accurate value for minimum spectrum requirements in the UHF band. However, the results obtained from the simulation clearly show that the objective of providing broadband coverage in rural areas with a data rate of 50 Mbps can be achieved, at least in part, but only by providing a tranche of spectrum of 50 to 100 MHz in the downlink alone and by implementing a relatively high base station density for rural regions. Of course, the scaling effects associated with spectral efficiency and base station density could also facilitate the allocation of part of the spectrum for other radio services, such as PPDR or PMSE, without limiting the development opportunities for commercial mobile services in the long term. It does not appear to be absolutely necessary to have overlapping supply by various mobile operators to ensure coverage of sparsely populated rural areas. One possible solution to achieve the required large bandwidths could be to bundle the spectrum of several mobile operators. However, the necessary regulatory framework would need to be in place for this purpose.

5 Investigations into spectrum requirements for broadband applications for Public Protection and Disaster Relief (PPDR), the military services and operators of critical infrastructures

Taking a similar approach to our investigations into commercial mobile services, we also studied the different perspectives and facts available on spectrum requirements in this area and the frequency ranges currently under discussion. The main sources for our investigations were the publically available CEPT ECC FM49 documents and the published results of a scientific study funded by the German Ministry of Economy and Technology[6]. While several studies on PPDR[7] spectrum requirements are publically available, there are no publications on the spectrum requirements of the military services. At the time of publication, the authors of this report had unfortunately not received comments on the "Mobile Media 2020" discussion paper [64] from the German Ministry of Defence. During a consultation held at the German Ministry of Economy and Technology on 12 November, 2012, a German Ministry of Defence spokesperson signalled a willingness to discuss spectrum band sharing with PPDR agencies.

5.1 Background on PPDR spectrum usage in Germany

Current status of PPDR in Germany

A total spectrum of 12.7 MHz in the 34.35 - 39.85 MHz, 74.205 - 87.265 MHz and 165.2 - 173.99 MHz frequency ranges is available for analogue PPDR radio communication in Germany [82]. In addition, a TETRA-based digital radio network for PPDR is currently being developed. It is scheduled for completion at the end of 2014 and will consist of approx. 4,500 base stations. As of mid-November 2012, 3,456 of these were operational and 2,580 were integrated in the network [69]. Figure 5-1 shows the current deployment status. The digital radio network is designed for voice communication and narrowband data communication at rates of up to 28 kbps [70]. The digital radio network will operate in the 400 MHz band within the 380-385 MHz and 390-395 MHz duplex bands. It will be used by state and federal police, fire services, rescue services, disaster control and civil defence, the German Federal Agency for Technical Relief (THW) and customs. The network is designed to cater for 500,000 users. As of September 2012, 240,000 users were already registered.

Applications for broadband systems

For agencies with security responsibilities for Public Protection and Disaster Relief, there is a need to communicate high-speed, mission-critical data from applications such as helmet cameras, video transfer to control centres, links from mobile operation units to central databases and transmission of location updates from helicopters. In addition, increasing numbers of unmanned drone vehicles and aircraft are being deployed. A study conducted in 2011 by the firm IABG on behalf of the German Ministry of the Interior [70] reported on the

[6] Scientific study by Central Innovation Programme for SMEs (ZIM) No. KF2340906
[7] The term used in German is Behörden und Organisationen mit Sicherheitsaufgaben (BOS)

broadband system requirements. For this study, IAGB conducted interviews with 20 organisations: 18 predefined communication scenarios were assessed, based on their technical requirements and their relevance to each organisation.

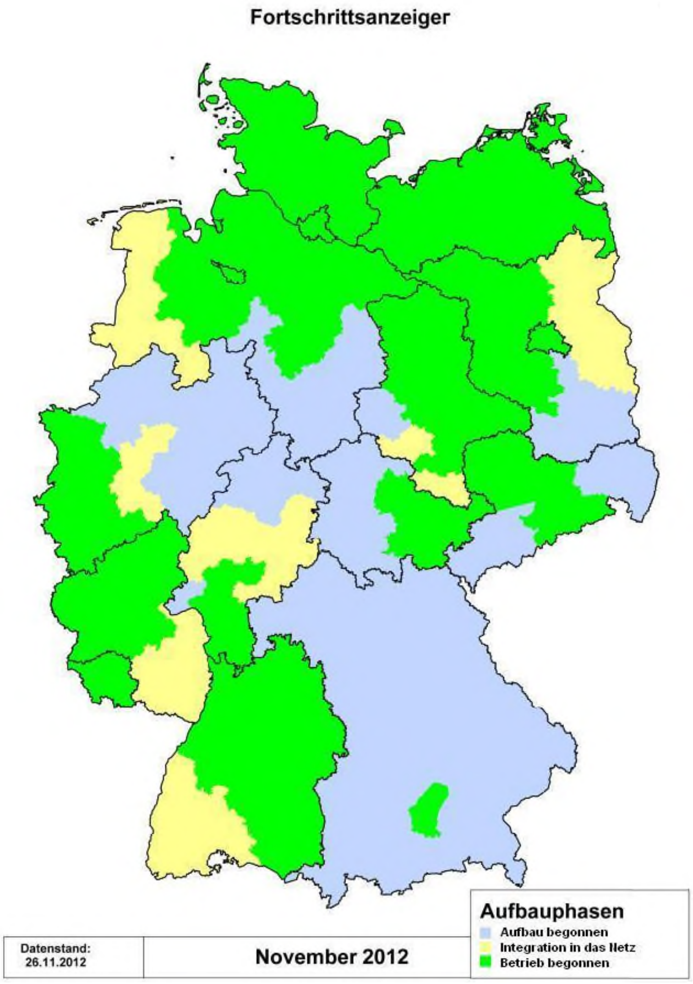

Figure 5-1: Implementation of digital PPDR radio communication in Germany (as at November 2012) [69]

The 18 communication scenarios were divided into six scenarios in each of the categories A (Normal Operation of the PPDR Agencies), B (Cultural events or Sports Mass Events and Demonstrations) and C (Natural and Major Disasters). A total of 78 relevant communication scenarios was identified. According to the study, 75% of the relevant scenarios were considered by the organisations to be mission-critical: that is, where a breakdown in communication would directly endanger human lives. A high level of availability was required in 90% of the relevant scenarios. The communication scenarios were also defined according to their required data transmission rate and ranges. In a key finding, it was determined that data rates of several Mbps and ranges of more than 10 km in some cases would be required in all three categories, even for normal operations.

In summary, the combined requirements of high availability, high data transmission rates and large ranges suggest that at least part of the spectrum needs for PPDR broadband use should be provided at frequencies below 1 GHz. The high availability requirements of PPDR systems also underline the need to allocate dedicated PPDR spectrum. There are many risks attached to sharing usage with commercial networks. The German Federal Association of Professional Mobile Radio (*Verband Professioneller Mobilfunk e.V.*) also highlighted the need for dedicated spectrum in the case of mission-critical communication in their response [81] to the "Mobile Media 2020" discussion paper.

Technologies to be considered for broadband usage

The above mentioned IABG study [70] also considers which technologies or frequency ranges could be used to implement the communication scenarios. The technologies listed are: WLAN (802.11 a/g/n/p); directional signals; satellite communication; an unspecified VHF radio system for indoor communication; LTE. Although WLAN is the preferred option for ad hoc communication, especially in the 5GHz band, LTE is more suitable for blanket broadband coverage. The US regulatory authority FCC was an early adopter of LTE 700 for broadband PPDR communication [71]. Following reallocation of further spectrum in February 2012, there is now availability of 2x10 MHz in the frequency bands 758 - 768 MHz and 788 - 798 MHz for broadband PPDR services in the US [85]. The US decision gave rise to discussions in Germany and Europe, which in turn resulted in feasibility studies, e.g. [72]. Furthermore, the US decision to use LTE 700 for broadband PPDR communication sets the trend for other countries, for two reasons: First, the sheer size of the US market could result in economies of scale for both infrastructure and user end devices, especially since it is possible to reuse components from commercial mobile technology. Second, standardisation centred on 3GPP activities is underway, aimed at specifying PPDR-specific performance features, such as group communication in future LTE releases [74].

5.2 Current perspectives on PPDR spectrum requirements

In Germany, initial studies into spectrum requirements for PPDR applications were conducted in 2010 and 2011 [70], [73]. The Institute for Communications Technology at TU Braunschweig completed a feasibility study on the use of LTE for PPDR applications in 2011. This formed part of a scientific study carried out with Rohde&Schwarz PMR GmbH[8] and funded by the German Ministry of Economy and Technology through its Central Innovation Program for SMEs (ZIM). At European level, the CEPT ECC FM49 working group is discussing the spectrum requirement and candidate bands for broadband PPDR systems. The following is a summary of the study findings and the current status of the CEPT ECC FM 49 working group discussions.

IABG study [70]

Based on the information gathered in interviews with organisations, this study estimated spectrum requirements as follows:

- 60 MHz spectrum (20 MHz in the downlink, 40 MHz in the uplink) for LTE
- 60 MHz spectrum for adhoc communication at 5 GHz

[8] Now Hytera Mobilfunk GmbH

- 14 MHz in the VHF band below 80 MHz for temporary coverage inside buildings

Unfortunately this estimation of spectrum requirements is not consistent for LTE Release 8 and LTE Release 10. The WIK study, described below, addresses the data traffic assumptions made in the IABG study and derives considerably lower spectrum requirements.

WIK study [73]

The WIK study carried out on behalf of the German Ministry of Economy and Technology verifiably derived the following spectrum requirements for broadband PPDR:

- 25 MHz (15 MHz in the uplink; 10 MHz in the downlink) below 1 GHz for systems using IMT-Advanced technologies, e.g. LTE Advanced or IEEE 802.11m (WiMAX)
- Continued use of spectrum in the 5150 - 5250 MHz band for ad hoc applications augmented by further spectrum in the 1452 - 1479 MHz band
- Minimum of 15 MHz (unpaired) in the 1 - 5 GHz range for air to ground links

In calculating the spectrum requirements below 1GHz, the data traffic demand for various communication scenarios was first estimated. The total data traffic for a single event in normal operation (see Category A above) was estimated at 1200 kbps in the downlink and 1900 kbps in the uplink. It is assumed that such an event occurs at the cell edge and another simultaneous event occurs some distance from the cell edge. Furthermore, since availability is a high priority for PPDR, it is also assumed that the transmission method with the highest immunity to interference (QPSK, code rate 78/1024) must be applied at the cell edge. This method has a spectrum efficiency value of 0.15 bps/Hz. It is assumed that the position of the second event was so far from the cell edge that a transmission method with a spectrum efficiency of 1.5 bps/Hz could be used. As a result, spectrum needs of 14 MHz in the uplink and 8.8 MHz in the downlink can be implied. Based on channel widths of 5 MHz for LTE, the study concludes spectrum requirements of 15 MHz in the uplink and 10 MHz in the downlink.

The WIK study and the spectrum requirements thus deduced were used as the basis of a submission made to CEPT ECC FM 49 [75] by the German authorities [75].

Feasibility study by TU Braunschweig [72]

The aim of this study was not to investigate spectrum requirements, but to demonstrate the basic feasibility of providing broadband PPDR services using LTE on VHF. This focus influenced the choice of scenarios and the assumptions made. The study was based on ray tracing simulations carried out in a city centre scenario. The hypothetical network assumed base station aerials similar in density and height to those in typical mobile networks; three networks with varying base station density were investigated. A number of day-to-day communication scenarios involving the police and a major fire were investigated. Availability of > 95 % for routine day-to-day police operations could be achieved using 2 x 5 MHz. In the case of the communication scenario involving a major file, availability could be considerably increased using 2 x 10 MHz instead of 2 x 5 MHz, but availability of 95% was not achieved. To increase availability, further measures would be required, e.g. the use of vehicular repeaters. However, the study findings show that the spectrum requirements established in the WIK study are broadly sufficient to provide broadband PPDR services using LTE.

CEPT ECC FM49

The Correspondence Group Spectrum Requirements was set up within CEPT ECC FM49 to determine spectrum needs for broadband PPDR services [76]. Preliminary results for the spectrum needs are not yet available. However, the method used in the WIK study was used as reference, while the WIK assumptions for the link budget were also applied.

5.3 Possible candidate bands

5.3.1 Current discussions in CEPT ECC FM49

CEPT ECC FM49 is examining various candidate bands for broadband PPDR services. A brief summary of the current status as described in [77] is below.

84.5 to 108 MHz

This frequency band was introduced by the Swiss authorities as a long-term solution (20 years) and was justified by a potential digital radio dividend [78]. This band is not a suitable solution in the short or medium term.

380 to 400 MHz

This band is partly used by NATO and by TETRA, a voice communication system for PPDR which should continue to exist alongside a broadband PPDR solution. Country-specific solutions may be possible but harmonisation at European level would be difficult to achieve.

400 to 470 MHz

Bands in the 410 - 430 MHz and 450 - 470 MHz bandwidths are available in individual countries. However, harmonisation at European level would be difficult to achieve.

470 to 698 MHz

This band is used by terrestrial television and there is no allocation for mobile services. Therefore cognitive and country-specific solutions would only be possible where at least part of this band is no longer required for terrestrial television.

694 to 790 MHz

This band is allocated to mobile services in ITU regions 2 and 3. Item 1.2 on the agenda of the World Radiocommunication Conference (WRC) in 2015 addresses the option of also allocating this band for mobile services in Region 1. Based on current discussions, solutions residing in this band are most likely to achieve harmonisation at European level. Proposals for concrete band plans [79], [80] in this frequency band are already available. The bands for broadband PPDR services would occupy the lower end of the band. In addition, efforts are being made to find a solution that would enable flexible distribution of bands between broadband PPDR services and commercial mobile services in various countries.

790 to 862 MHz

This is the digital dividend band already allocated to commercial mobile services in Germany and other European countries. Country-specific solutions are possible in this band, while harmonisation at European level is not.

Bands above 870 MHz

This list of bands also includes the GSM bands as well as the T-DAB bands from 1452 to 1479 MHz and the UMTS-TDD bands at 1900 - 1920 MHz und 2010 - 2025 MHz, which many countries do not use. The GSM bands are not serious contenders due to their intensive usage by commercial mobile services. The frequency ranges and associated propagation conditions in the T-DAB and UMTS-TDD bands make these are more suitable candidates for ad hoc communication scenarios.

5.3.2 Prospects for PPDR services in the 400 MHz and 700 MHz frequency bands

According to current discussions in CEPT ECC FM49, the 400 MHz band (380 - 470 MHz) and the 700 MHz band (694 - 790 MHz) are the only realistic candidates for further PPDR services. Although harmonisation of the 400 MHz band at European level (particularly in several NATO member states) would be difficult, there is support within the CEPT for this solution. The French government in particular supports this proposal [81], citing the following advantages:

- The current narrowband solutions (TETRA) operate in precisely this frequency range. Therefore the existing sites could be reused, with positive implications for the investment required.
- Since both the armed forces and operators of private professional mobile networks use frequencies in this band, economies of scale for user end devices are expected.
- The availability of several possible LTE bandwidths could enable flexible refarming, possibly resulting in the complete replacement of TETRA by LTE.

To what extent TETRA should be completely replaced by LTE is unclear: some manufacturers are also working on solutions to connect TETRA networks with LTE networks. Strategies of this nature were presented at the TETRA World Congress in 2011 [82].

On the other hand, the 700 MHz band has many advantages:

- The decision taken in the US to use the 700 MHz band for PPDR applications also resulted in economies of scale that are possibly greater than those described above for the 400 MHz band, due to the size of the US market. This could also influence the availability and cost of infrastructure equipment, potentially offsetting higher site costs to some extent.
- Broadband solutions are specifically designed to achieve high data rates, while multi-antenna systems are also required for the end devices to achieve this goal. However, due to the larger wavelength in the 400 MHz band, it is increasingly difficult to

implement multi-antenna systems at lower frequencies, specifically in the case of end devices.

Although CEPT ECC FM49 has not yet made a final decision on the selection of candidate bands, its experts favour the 700 MHz band, especially because harmonisation at European level is far more likely here. CEPT ECC FM49 is already discussing concrete band plans for this particular scenario [79,80]. The recommended actions outlined in Chapter 7 of this report therefore focus solely on relevant band plans for this scenario. If CEPT ECC FM 49 decides in favour of the 400 MHz band instead, the band plans can be modified accordingly.

5.4 Current discussions on spectrum requirements for military applications

The "Mobile Media 2020" discussion paper [64] also refers to spectrum needs of 2x15 MHz for the Federal Armed Forces. It justifies these needs because the radio communications systems currently used by the Federal Armed Forces will not adequately fulfil future communication requirements. Furthermore the paper states that future communication should be covered by high-mobility cellular LTE networks in frequency ranges under 1 GHz. Unfortunately there are no studies or publications currently available to support these spectrum needs.

In our opinion, a nationwide allocation of spectrum to provide wide-area penetration for a LTE-based military network would only make sense if this wide-area LTE network is developed by the Federal Armed Forces. Naturally the decision to finance this type a cellular network rests with the government. The following aspects should be considered in assessing the need for a nationwide network for the Federal Armed Forces:

- Since the Federal Armed Forces are primarily deployed abroad, a nationwide cellular network would be of little or no use in helping them fulfil their duties. We should note here that the Federal Armed Forces do not currently have a nationwide narrowband cellular network and also that they recently relinquished spectrum below 1 GHz, which is included, for example in the frequency band now used for E-GSM.
- The Federal Armed Forces can also be deployed in Germany in very exceptional circumstances (see press release of the Federal Constitutional Court on August 12, 2012 [85]). The tasks carried out in these exceptional cases, like, for example, in the largest deployment of the German army to date during the flooding of the river Oder in 1997, involving 30,000 soldiers [86], are comparable with PPDR tasks. Shared usage of the PPDR network in these cases could therefore be considered.
- For training and military exercises, e. g. in barracks and on military training grounds, the use of a cellular LTE network seems appropriate. However, shared usage of the PPDR network or at least of the PPDR spectrum would also be an option.

5.5 Spectrum requirements for operators of critical infrastructures in the energy, transport and industry sectors

In commenting on the "Mobile Media 2020" discussion paper [83], the German Association for Professional Mobile Radio called for dedicated spectrum to be assigned to broadband data applications for operators of critical infrastructures in the energy, transport and industry sectors. Operators of the systems currently use both analogue radio systems and TETRA digital radio systems for voice communication and narrowband data applications; they can use dedicated spectrum in the 410 - 430 MHz frequency band to this end. No studies or information on possible communication scenarios and the corresponding spectrum needs were available to the authors of this report. We therefore cannot comment definitively on the spectrum requirements for operators of critical infrastructures in the energy, transport and industry sectors. To fulfil possible spectrum needs, the following options should be examined in detail:

- Option 1: Allocation of dedicated spectrum in the UHF band. In relation to the band plans proposed in Chapter 7, this option would adversely affect the allocation of spectrum for commercial mobile communication, PPDR or PMSE.
- Option 2: Allocation of spectrum above 1 GHz. This spectrum would be particularly suitable for operators of low range networks, e.g. on a factory premises.
- Option 3: Sharing of commercial mobile networks for non-critical applications, e.g. transmission of broadband passenger information on local public transport.
- Option 4: Sharing at least part of the spectrum allocated to PPDR for critical applications. For example, part of the spectrum could conceivably be dedicated to PPDR, with another part of the spectrum could be made available for shared use with operators of critical infrastructures.

Combinations of the above options may also be considered.

5.6 In summary

Based on the studies conducted to date, dedicated spectrum of the order of 20 to 30 MHz is required to establish a broadband PPDR network. The exact spectrum requirements are currently being determined by CEPT ECC FM 49. Based on the most detailed studies carried out to date, spectrum requirements of 25 MHz are assumed for Germany. There are no quantifiable spectrum requirements currently available to evaluate usage by the armed forces or by operators of critical infrastructures in the energy, transport and industry sectors. Of the frequency bands mentioned in Section 5.3, the 694-790 MHz band is the most suitable candidate for spectrum harmonisation for broadband PPDR at European level.

In the absence of a final determination of PPDR spectrum requirements and quantifiable spectrum requirements for the armed forces and operators of critical infrastructures in the energy, transport and industry sectors, this report examines the three options below. These are all in the 694-790 frequency range and are discussed in Chapter 7 in the overall context of spectrum needs for other mobile communication services:

- *Option 1:* Dedicated allocation of 2 x 5 MHz in the 694-790 MHz band
- *Option 2:* Dedicated allocation of 2 x 10 MHz in the 694-790 MHz band
- *Option 3:* Dedicated allocation of 2 x 15 MHz in the 694-790 MHz band

As regards the use of LTE by the Federal Armed Forces, we recommend sharing PPDR frequencies. Assuming these frequencies will be shared in this case (and also possibly shared with operators of critical infrastructures in the energy, transport and industry industries), and based on the spectrum requirement of 25 MHz determined in the WIK study, the authors of this report favour options 2 and 3 above.

6 Innovative approaches for the sharing of spectrum usage by terrestrial television and mobile networks

While PMSE systems and terrestrial TV broadcasting systems have shared the same frequency spectrum for decades, terrestrial broadcasting and mobile networks have not yet adopted the same approach to shared spectrum usage. In light of the recommendations proposed at WRC 2012 to examine the co-primary use of spectrum, it appears now timely to focus research and development on new concepts for the coexistence of various systems in the same frequency spectrum. The Institute for Communications Technology of TU Braunschweig has been pursuing two different research directions for many years with this goal in mind. One research direction is in the area of dynamic broadcasting. This approach retains terrestrial TV broadcasting in its traditional form, e.g. via DVB-T or DVB-T2, but does not use all the channels previously allocated to television at all times. The second area of research is in the use of transmitter networks. Until now, these have been used for terrestrial TV broadcasting, as an enhancement of cellular (LTE-Advanced) services. This method is known as tower overlay.

6.1 Tower overlay for LTE networks

The concept of tower overlay for LTE networks has emerged in the wake of the increase in data volume within mobile networks and the decision at this year's World Radiocommunication Conference (WRC 2012) to call for the co-primary use of the 700 MHz band (694-790 MHz) by mobile services and terrestrial TV broadcasters after the next World Radiocommunication Conference in 2015. Tower overlay has the following objectives:

1. To make the most efficient use of the frequency resources available to mobile services, particularly for transmitting video content, in order to reduce the frequency requirements of mobile network operators
2. To reduce provision costs for the (media) content provided over mobile networks
3. To avoid multiple transmissions of live video in cellular mobile networks
4. To use infrastructures previously used by broadcast networks to address LTE-Advanced end devices

6.1.1 Efficient spectrum usage through the deployment of point-to-multipoint transmission (P2MP)

To date, all user data in modern mobile networks is transmitted using separate, user-specific point-to-point connections (P2P) to the individual end devices. With this method, each individual connection is allocated to a section of the available spectral resources in a mobile radio channel. Consequently, in the case of identical data which is requested by various users simultaneously or within a certain (short) period of time, this data must be transmitted several times and thus occupy multiple resources in the radio channel. In view of the dramatic increase in video usage on mobile end devices, as forecast by the Cisco VNI

Mobile Study 2012 [33] for example, it must be assumed that this phenomenon will occur at an increasing rate as a result of the consumption of live video, thus putting pressure on mobile networks.

The redundancy caused by multiple transmissions of identical data can be prevented by the systematic use of point-to-multipoint (P2MP) communication. This means that multiple users within a coverage area can be supplied with the requested data using one individual data stream. While the required frequency resources for individual point-to-point communication scale with the number of users, these resources are entirely independent of the number of users in P2MP communication.

P2MP communication is particularly advantageous for live broadcasts, such as live TV, radio, live streams from the Internet, etc. These broadcasts are consumed by all users (almost) simultaneously. They include (radio and TV) programmes with high audience market shares and events of wide general interest, such as major sporting events and news programmes. For example, very high audience figures were recorded for the Olympia Live content covering the 2012 Olympic Games in London, which was broadcast over the ARD and ZDF Internet platforms [88]. If broadcasting live TV over the broadcast transmitter networks as outlined in Section 2.3.3 should become a reality, the transmission of live video within the mobile networks will play an even more important role, as it will then be the only mode for reaching audiences that are currently still reached by USB TV reception, DVB-T receivers in the car, etc. As a result, there is a danger that, without innovative expansion of the mobile networks, live video content will need to be broadcast multiple times in the P2P process. The implementation of the eMBMS enhancement specified for LTE will only be of little assistance in this regard. eMBMS also relies on (small) mobile cells and does not allow cross-provider transmission. Specifically, this means that in extreme cases, even after the implementation of eMBMS, each of the four network operators in Germany would have to provide the same live video content simultaneously in every network cell. The switchover to an efficient P2MP solution – particularly for television programmes with high market share – is therefore vital.

6.1.2 Efficient point-to-multipoint transmission within mobile networks through deployment of a tower overlay

A further disadvantage of eMBMS is the specification’s prescribed coexistence of this service with P2P data within a shared carrier. This is because the technology aims to guarantee simultaneous usage of P2MP and P2P at all times, so that, for example, users can receive an incoming telephone call while consuming live TV over eMBMS. Consequently, only certain areas (subframes) of an LTE carrier can be used for eMBMS, thus severely impairing the efficiency of eMBMS as a result of the following issues:

- LTE carriers cannot be used effectively for a dedicated eMBMS transmission, as a maximum of 60% of available resources are available for such services. In such scenarios, the remaining resources must be reserved for P2P connections.
- The eMBMS transmission is linked to the more or less small-cell infrastructure of the mobile networks, whose operation, compared to a traditional broadcast infrastructure

consisting of a few powerful transmitters typically with a distance between them of around 60 km in Germany, is more costly ([89], [90], [91]).

The concept of the tower overlay (Figure 6-1) was developed with the objective of achieving the most efficient point-to-multipoint distribution, particularly of live media content, to LTE end devices. Dedicated point-to-multipoint carriers, which contain only point-to-multipoint data, are transmitted using powerful transmitters, like those previously used solely for terrestrial TV broadcasting.

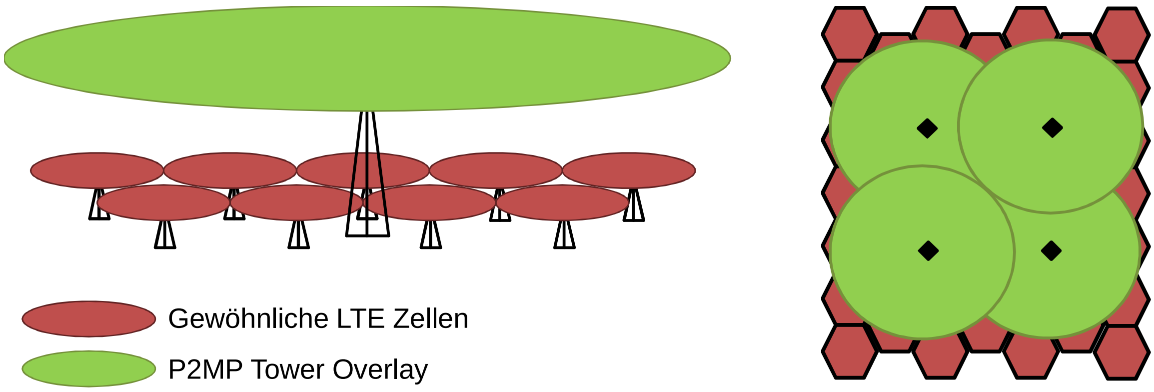

Figure 6-1: Tower overlay concept for LTE

Compared to small cell networks, the approach presented here facilitates the more cost-effective transmission of popular content within mobile networks. Approaches exist for the 3GPP (Third-Generation Partnership Project) LTE standard [92] and studies have been conducted about potential specific carrier structures [93] for the necessary dedicated carrier.

To continue ensuring the simultaneous reception of P2P and P2MP data, one of the technologies that will be in demand will be carrier aggregation, together with LTE-Advanced (enhancement of the LTE standard). Carrier aggregation involves bundling of up to five LTE carriers from potentially very different frequency ranges into one overall carrier, which increases the overall available data rate in a cell. Standard LTE carriers are thus bundled with dedicated P2MP carriers to guarantee the simultaneous availability of P2P and P2MP services. With appropriate signalling to the LTE carriers, end devices are aware of the existence and exact location of these P2MP carriers. The innovative approach advocated by the Institute for Communications Technology of TU Braunschweig is as follows: rather than limiting carrier aggregation to simply using different carriers within a traditional cellular network, carriers can also be integrated to provide wide-area coverage.

Figure 6-2 illustrates a potential scenario with a local LTE carrier containing signalling information and user-specific data, which is broadcast over unicast and the aggregation of a dedicated carrier for P2MP services [94].

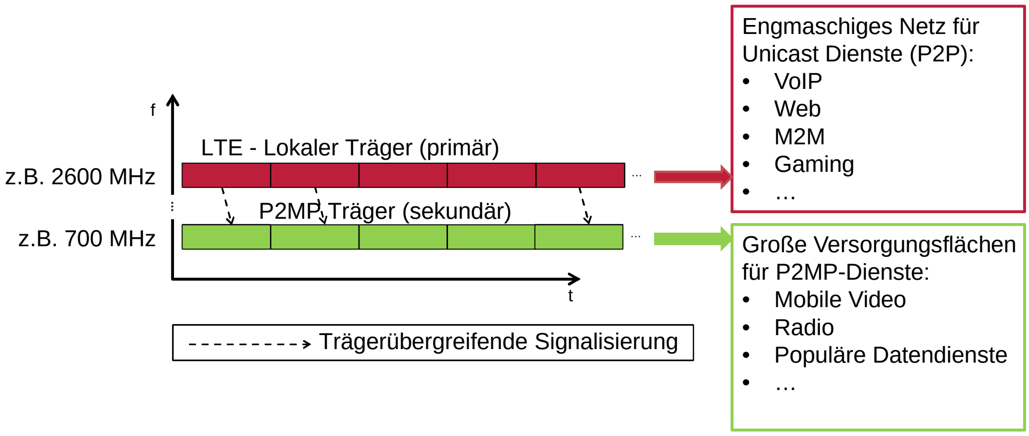

Figure 6-2: Potential scenario for the aggregation of various LTE carriers

To be able to provide the total number of mobile users within the entire coverage area of a tower transmitter with popular content, irrespective of provider, the mobile network operators should agree on the possibility of cross-provider usage of such a P2MP carrier. It does not seem practical, for example, that the four national network operators each broadcast their own live TV content, when overall spectrum requirements could be reduced if they shared the use of a tower overlay. The mobile network operators must cooperate and coordinate among themselves to optimise use of the existing resources and reduce the demand for additional frequency spectrum. If the mobile network operators also take into consideration the potential reduction in operating costs to be gained from using a tower overlay, bearing in mind the predicted increase in future data traffic (in mobile networks, the costs scale with the data volume), they will be obliged to investigate concepts that will help minimise their own operating costs.

6.1.3 Using existing broadcast technology for the tower overlay

A tower overlay can be implemented using DVB-T2, for example. With its Future Extension Frames (FEF) feature, this current digital broadcast standard allows you to embed system enhancements within a DVB-T2 data carrier in the time multiplex [95]. These frames could also be used to add new broadcast-specific services to the DVB-T2 standard or to embed other broadcast standards, such as a dedicated P2MP carrier for LTE. The corresponding broadcasting and mobile end devices must also be capable, through the appropriate signalling, of decoding the DVB T2 signal only within the periods in which a broadcast corresponding to their standard takes place. An LTE-capable smart phone therefore does not have to be equipped with an additional DVB-T2 receiver. Figure 6-3 shows the familiar and enhanced system from Figure 6-2. Using a hybrid modulator installed on a transmitter, the data from both standards – DVB-T2 and LTE – are modulated in the time multiplex on a shared carrier.

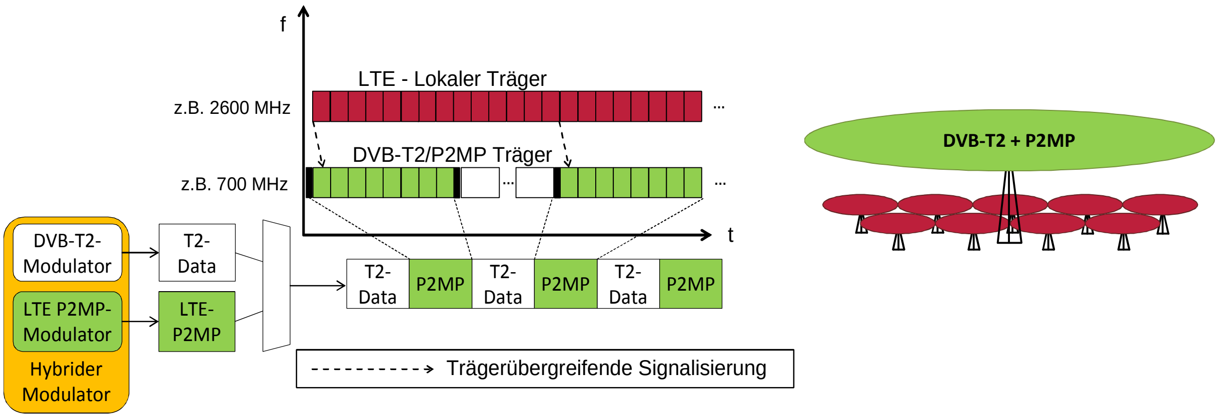

Figure 6-3: Example of carrier aggregation of an LTE downlink signal in a DVB-T2 carrier

The share of available resources in the DVB-T2 signal for LTE can be varied. This means that the various demands on the data rates needed for both standards can be met and, in extreme cases, the DVB-T2 signal can be used (almost) entirely for an LTE tower overlay.

The DVB-T2 Future Extension Frames therefore offer the option of co-primary frequency usage by terrestrial TV broadcasting, including a purely downlink solution of a tower overlay for LTE. The available resources of a carrier can therefore be divided variably among the two broadcast standards. In addition, both sides can benefit from the subsequent sharing of operating costs through the shared use of a single tower infrastructure. The objective of co-primary spectrum usage can be achieved.

6.1.4 Summary

The efficiency of mobile communications systems can be optimised by using P2MP in providing media content. Compared to user-specific P2P connections, the transmission of frequently requested data on dedicated P2MP carriers can reduce the total broadcast resources required. If a tower infrastructure is used, these carriers can be provided much more cost effectively than by using eMBMS within a cellular mesh network. Further development of the concept proposed by the Institute for Communications Technology at TU Braunschweig is required before we can make more definitive statements in relation to improving spectrum efficiency through P2MP and reducing costs through a tower overlay. Ideally, the concept would be developed in collaboration with mobile network operators. In Germany, the performance of a P2MP tower overlay could be further enhanced if the four German network operators cooperated and shared access to a single P2MP carrier.

6.2 Dynamic broadcasting

If we assume that terrestrial TV distribution develops according to the scenario described in section 2.3.2, a number of options still arise for the co-primary use of frequency spectrum from the “dynamic broadcasting” system developed by the Institute for Communications Technology of TU Braunschweig. With this system, TV content is no longer broadcast exclusively over a terrestrial TV transmitter network but also via a separate broadband network. The aim is to achieve the most efficient use of the terrestrial TV spectrum by deploying innovative methods for broadcasting media content.

Dynamic broadcasting also represents a potential future for television broadcasting. Television receivers have a tuner for receiving terrestrial TV via DVB-T and/or DVB-T2, are connected simultaneously to the broadband Internet and have an integrated computer hard drive. Now, all broadcast content no longer needs to be transmitted live over the terrestrial transmitter network. TV programme providers should still have the option of providing TV programmes as they did in the past and retaining the familiar television experience for audiences, but will less frequency spectrum and less electrical energy in the process.

Dynamic broadcasting facilitates the distribution of TV programmes using a combination of terrestrial transmission networks and broadband networks. It means that some content is broadcast in real time and some is broadcast before the actual broadcast time – in real time or using real-time compression. This content is recorded on the hard drive of the receiver and is available for playing out in accordance with the relevant signalling by the programme provider. It can also be used more than once, if – as is not unusual these days – content is repeated the following day, for example. The programme multiplexes on the various broadcast channels, the allocation of transmission frequencies and the attributes of the TV stations are also changed dynamically. The playout and network management provides solutions for signalling the diverse, dynamically changed parameters to the end device.

In addition to receiver tuners for digital television, the end device for dynamic broadcasting also has Internet access and an integrated computer hard drive. Using complex control software, the end device displays television programmes in the usual, familiar way, although the content displayed is provided partly by the receiver tuner, partly via Internet access and partly by the hard drive. Signalling information, which is delivered over the transmission paths, triggers switching between these receiver paths.

In dynamic broadcasting, the frequency spectrum is no longer constantly needed for television broadcasting. At times, it can be released for (secondary) usage by independent wireless broadband networks. Dynamic spectrum databases are one of the methods used to signal the availability of spectrum to secondary users.

Figure 6-4 shows the structure of a dynamic broadcast system.

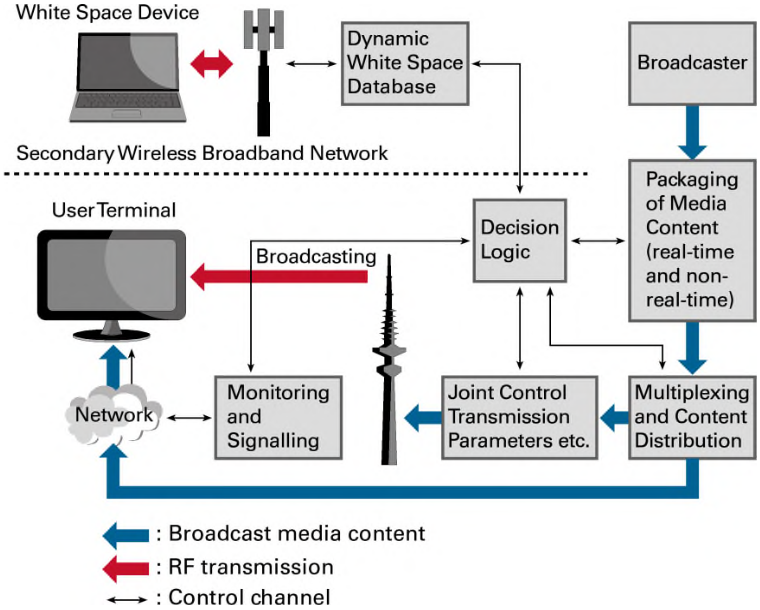

Figure 6-4: Dynamic broadcasting system overview

A certain proportion of the spectrum can be temporarily allocated to help optimise the system through the network logic, thus allowing secondary users to plan ahead with certainty when implementing their own radio network services. For this purpose, the users are provided with information about available spectrum resources, including the duration of their availability. Available frequencies can be signalled as such via the terrestrial transmitter network or over a network, for example by means of a database system. Interruptions caused by interference can be avoided by generating and allocating white spaces in the spectrum, in a controlled manner. The operational reliability of both coexisting networks ("television broadcasting" and “wireless Internet”) can thus be ensured.

The entire, operational system was presented for the first time at IFA 2012. Various publications describe all aspects of the solution,

e.g. [96], [97], [98], [99], [100].

7 Recommendations and courses of action

This expert report addresses the future spectrum requirements for terrestrial TV and mobile services and other radio applications in the 470-790 MHz frequency range. It also evaluates - from a number of socioeconomic and frequency technology perspectives - the options for shared frequency use, particularly in the 694-790 MHz frequency sub-band.

The starting point for this report was the Federal Ministry of Economics and Technology's Mobile Media 2020 discussion paper, which cited four different options for the future use of the 470-790 MHz frequency bands:

- Option 1: Retain the status quo in the 470-790 MHz frequency band until at least 2025
- Option 2: Assign the 649-790 MHz frequency sub-band to commercial mobile services as of 2016
- Option 3: Share the frequencies among terrestrial broadcasters (dynamic broadcasting) and other users (LTE, LTE-Mil, LTE-PPDR, PMSE) with the aim of establishing a commonly used network structure (CUNST)
- Option 4: Broadcasting abandons terrestrial television as a result of changed conditions.

This expert report begins by examining the requirements and basic conditions of different users and extrapolating their frequency requirements in the UHF band based on this information. The main conclusions are the following:

- *Terrestrial television*: Three potential scenarios are developed. Of these, only the scenarios "Switchover from DVB-T to DVB-T2" and "Phasing out of terrestrial TV broadcasting" are seen as realistic. These two scenarios, which correspond to options 2 (though only partially), 3 (also only partially) and 4 of the discussion paper, are considered below.
- *PMSE*: In the event that the "Phasing out of terrestrial TV broadcasting" scenario comes to bear, PMSE will require the allocation of dedicated spectrum.
- *Commercial mobile services*: The allocation of spectrum in the UHF range would help to cover the predicted total spectrum requirements and to support coverage of rural areas with broadband connections.
- *PPDR*: Dedicated spectrum in the order of 2x5 MHz to 2x15 MHz is needed. Ideally, this should be in the 700 MHz band based on greater opportunities for European harmonisation.
- *Military services and operators of critical infrastructures*: Currently, there are no quantified spectrum requirements for these users. If necessary, these requirements must be covered by the spectrum range provided for commercial mobile services or PPDR.

Based on these findings, various scenarios were identified and specific band plans were developed for these scenarios. These band plans also take into account the uncertainties faced by some individual users. Two scenarios, each with three or four band plan variants are discussed below.

***Scenario 1: Switchover from DVB-T to DVB-T2*.**

If there is a switchover from DVB-T to DVB-T2, it will be possible to use part of the 700-MHz band for other services, provided this is successfully coordinated with other countries outside Germany. This could happen in urban agglomerations starting around 2018 and be rolled out throughout Germany from around 2020. As part of this migration, hundreds of TV broadcasting stations would have to be modified. The concerns of cable operators who are currently operating networks that support both TV and Internet services in the frequency band under review must be taken into consideration. Operators of PMSE systems require frequency allocations outside the UHF band. For this scenario, this expert report proposes band plans that take account of mobile services and services for Public Protection and Disaster Relief (PPDS), and that provide for coexistence between various radio applications.

Depending on the spectrum requirements that still need to be determined for PPDR (2x5 MHz, 2x10 MHz or 2x15 MHz) , Figure 7-1 proposes three variants for band plans with different usage by PPDR or commercial mobile services, where a duplex gap of 9 MHz between the UL and DL is assumed. Bearing in mind the potential guard intervals at the upper and lower end of the frequency spectrum, the most efficient possible use of the spectrum can be achieved. Depending on the frequency requirements of operators of critical infrastructures, the bandwidths provided for PPDR or commercial mobile services can still be changed. For this scenario, cooperative use of the 470-694 MHz frequency band is proposed. In Chapter 6, the expert report presents research approaches that could tackle the increasingly pressing issue of cooperative or co-primary use of terrestrial frequencies for broadcasting and mobile services. It also calls for research and development support in this important area.

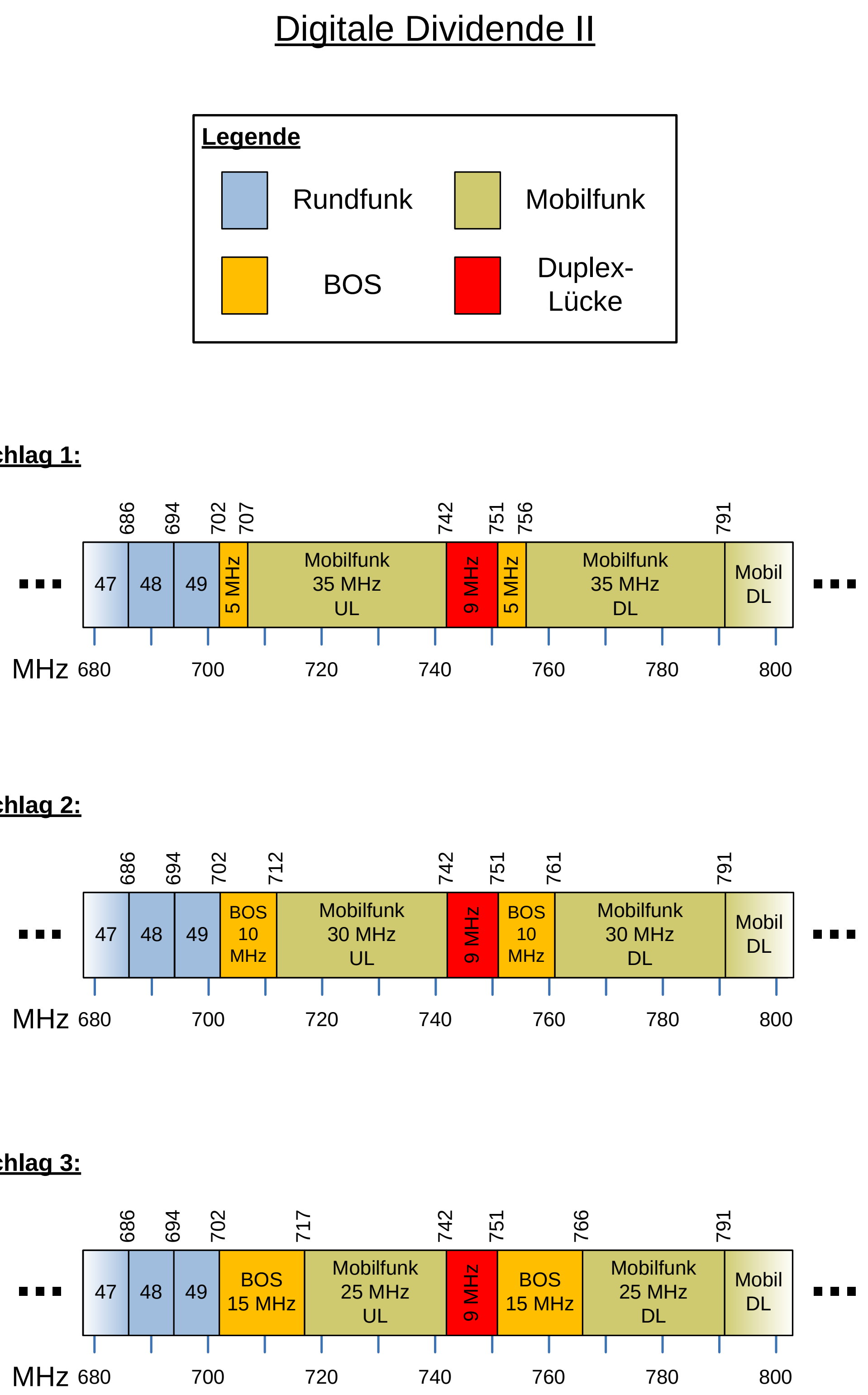

Figure 7-1: Band plans for different variants of usage by PPDR and commercial mobile services while retaining DVB-T/DVB-T2 in channels up to 49

Scenario 2: Phasing out of terrestrial TV broadcasting

If terrestrial TV distribution is phased out, which could be complete by 2019 under certain circumstances, band plans are presented for four variants. In this case, operators of PMSE systems require specially reserved frequency ranges. For broadcasting live video to portable and mobile receivers (including in-car receivers), innovative solutions beyond the current state-of-the-art for mobile communications will have to be found. The broadcasting of live video over and above the data volume limits specified by the mobile network operators in their client agreements should be facilitated and possibly linked to a "must carry" obligation and many other commitments. The tower overlay concept presented in Chapter 6.1 of this report offers one option for implementing this obligation. The four variants examined here take into consideration varying-sized allocations for PMSE, each with or without dedicated spectrum for implementing a tower overlay concept.

The four variants are illustrated in Figures 7-2 to 7-5. In variant 2, a duplex gap of 10 MHz is proving to be more beneficial. To minimise interference caused by spurious emissions from LTE end devices, PMSE is allocated to an associated spectrum block, which is interrupted only by the allocation of the bands for radio astronomy. Other PMSE usages could potentially be provided for in the duplex gaps. In addition, investigations would need to be conducted to identify available white spaces in the frequency bands used by commercial mobile services and their possible applications. To facilitate this type of usage, spectrum emission masks, which are more effective at suppressing the spurious emissions, would be beneficial, particularly in the LTE end devices. Variant 2 provides for a block of 2x15 MHz in the 700 MHz band. These spectrum requirements represent the upper limits of the spectrum requirements discussed in Chapter 5.

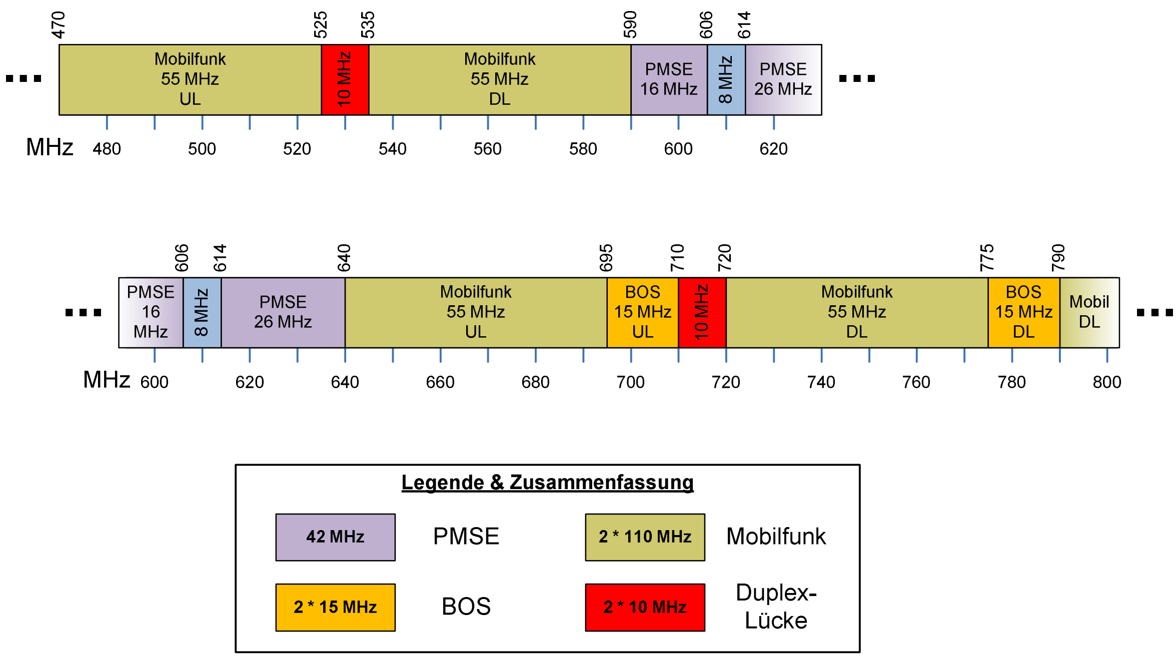

Figure 7-2: Band allocation when terrestrial TV broadcasting ceases – variant 1

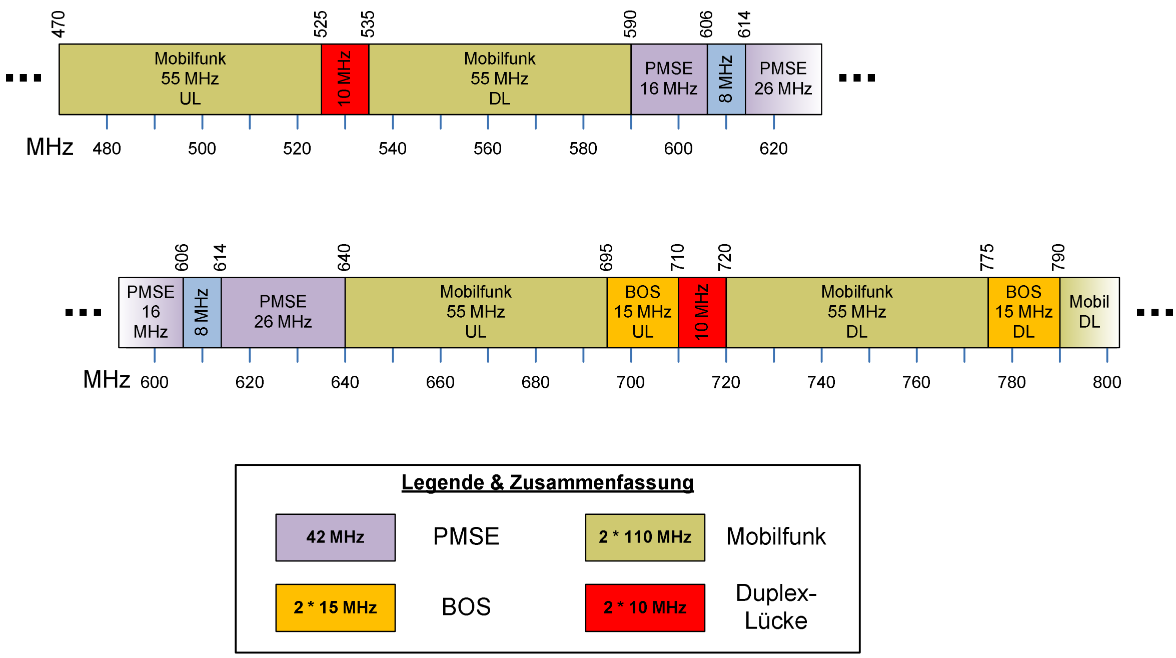

Figure 7-3: Band allocation when terrestrial TV broadcasting ceases – variant 2

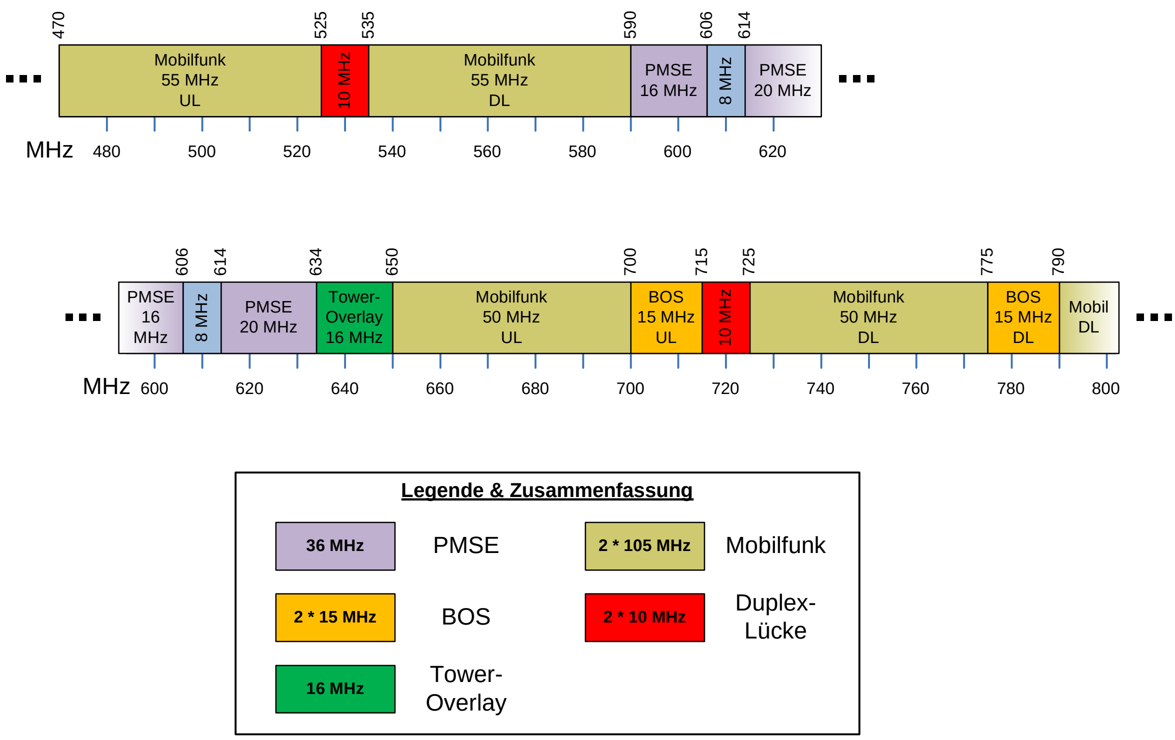

Figure 7-4: Band allocation when terrestrial TV broadcasting ceases – variant 3

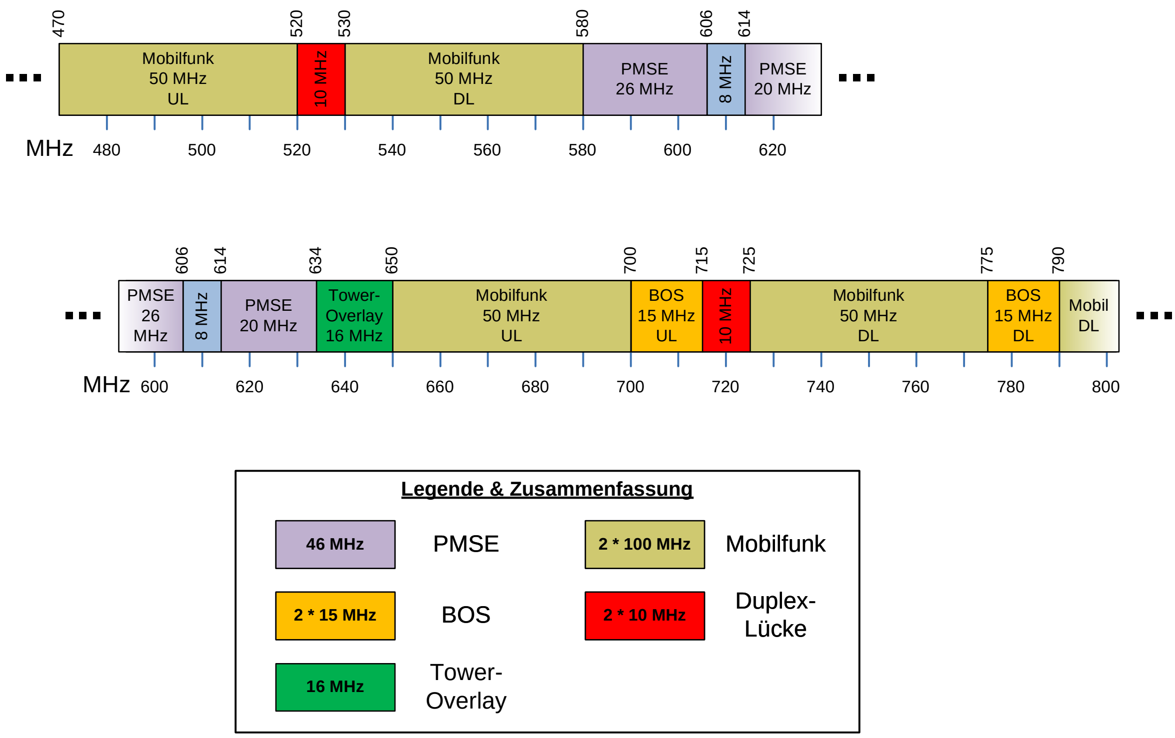

Figure 7-5: Band allocation when terrestrial TV broadcasting ceases – variant 4

Bibliography

[1] Reimers, U. (Hrsg.): DVB – Digitale Fernsehtechnik, Datenkompression und Übertragung. Springer-Verlag Berlin Heidelberg, 2008

[2] Lenkungsgruppe DVB-T Norddeutschland (Hrsg.): Renaissance der Antenne. Vistas media production, Berlin, 2004

[3] Mann-Raudies, Th.; Painter, M.: 1998 – 2008 10 Jahre DVB-T in Deutschland. Abschlussbericht der TASK Force DVB-T Deutschland von ARD und ZDF, am 24. November 2012, [Online]: ww.ueberallfernsehen.de/dvbtdownloads129.pdf

[4] Anonymus: Sender- und Programmliste Deutschland, [Online]: www.ueberallfernsehen.de/dvbtdownloads127.pdf, am 24. November 2012

[5] Rabe, R. (LPR Hessen): Persönliche Kommunikation, 21. November 2012

[6] Anonymus: DVB-T-Empfangsbereich deutschlandweit, [Online]: www.ueberallfernsehen.de/dvbtdownloads125.pdf, am 24. November 2012

[7] Rother, D.: Analyse der TV-White-Space-Verfügbarkeit in Deutschland. Master's thesis at Technische Universität Braunschweig 2012

[8] [EE11]: Electronic Communication Committee (ECC); European Conference of Postal and Telecommunications Administrations (CEPT): 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. [Online]: http://www.erodocdb.dk/doks/filedownload.aspx?fileid=3709&fileurl=http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP159.PDF, on 13 December 2012

[9] Digitalisierungsbericht 2012. Daten und Fakten Chartreport. September 2012. [Online]: www.die-medienanstalten.de/service/, on 24 November 2012

[10] Projektrat DVB-T2 Modellversuch Norddeutschland (Hrsg.): Terrestrik der Zukunft – Zukunft der Terrestrik. Shaker Verlag, Aachen, 2012

[11] ARD: Richtungsentscheidung der ARD zur Zukunft der terrestrischen Fernsehverbreitung. Press release from 12 September 2012, [Online] http://www.ard.de/intern/ard-fernsehen-empfang-antenne-dvbt/id=1886/nid=1886/did=2621234/14uo3fu/, on 25 November 2012

[12] Heimermann, B.: Media Broadcast – Vorschlag für ein DVB-T2-Migrationskonzept für Deutschland. Personal communication, 16 November 2012

[13] Bundesministerium für Wirtschaft und Technologie (BMWi): Monitoring zu ausgewählten wirtschaftlichen Eckdaten der Kultur- und Kreativwirtschaft. 2010 (abridged version).

[14] Deutsche Kommission Elektrotechnik Elektronik (DKE): AK 731.0.8 UHF-Frequenznutzung durch PMSE bei den Landtagswahlen in Hannover, Münster, Wiesbaden und der Bürgerschaftwahl im Hamburg. 2008.

[15] DKE AK 731.0.8: Beobachtung der Frequenznutzung im Rahmen des Eurovision Song Contest 2011. Eine Veranstaltung in Düsseldorf. December 2011.

[16] Ofcom: Ofcom and the London 2012 Olympic and Paralympic Games. 18 December 2012.

[17] Bettina Milz, Ministerium für Familie, Kinder, Jugend, Kultur und Sport des Landes Nordrhein-Westfalen: Statement Bettina Milz, MFKJKS NRW, 12 November 2012.

[18] Leibnitz Universität Hannover, Institut für Hochfrequenztechnik und Funksysteme: Report on the frequency resource requirements of Professional Wireless Microphone Systems in urban areas with respect to changing broadcasting allocation concepts. 29 October 2008.

[19] Bundesnetzagentur: Frequenznutzungsplan, August 2011.

[20] Bundesnetzagentur Vfg.91/2005: Allgemeinzuteilung von Frequenzen für drahtlose Mikrofone für professionelle Nutzungen in den Frequenzbereichen 790 – 814 und 838 – 862 MHz.

[21] Bundesnetzagentur Vfg.09/2011 zuletzt geändert durch Vfg. 23/2011: Allgemeinzuteilung des Frequenzbereichs 823 MHz – 832 MHz für den Durchsagefunk.

[22] Bundesnetzagentur Vfg.68/2003: Allgemeinzuteilung von Frequenzen für die Benutzung durch die Allgemeinheit im Frequenzbereich 863 MHz bis 865 MHz für drahtlose Mikrofone.

[23] Bundesnetzagentur Vfg.10/2011: Allgemeinzuteilung des Frequenzbereichs 1785-1805 MHz für Durchsagefunk.

[24] Holzer, N.; Schweda, S.: SOS Europe: Kultur im Wellental? Frequenz- und kulturpolitische Aspekte der „Digitalen Dividende“. MultiMedia und Recht, S. 795 – 801, December 2012.

[25] Association of Professional Wireless Production Technologies e.V. and Deutsche Kommission Elektrotechnik Elektronik (DKE): AK 731.0.8: Information zu einem gemeinsamen Messbericht von APWPT und DKE AK 731.0.8 - Untersuchung des LTE Störungspotentials auf den Betrieb von PMSE. 30 June 2012, [Online]: http://www.apwpt.org/downloads/lte-stoerungspotential-auf-mikrofone30062012.pdf.

[26] Association of Professional Wireless Production Technologies e.V.: PMSE strategy paper. Cultural Europe will not survive a second digital dividend. September 2011. Update September 2012.

[27] Association of Professional Wireless Production Technologies e.V.: Mobile Informationsgesellschaft der Zukunft. APWPT comment on BMWi consultation of 12.11.2012.

[28] Ein Forschungsprojekt zur Verbesserung der Frequenznutzung und Koexistenz für PMSE Systeme durch kognitive Verfahren. [Online]: http://www.c-pmse.research-project.de

[29] Puigrefagut, E.: The road to WRC-15. Tech-I, June 2012, [Online]: http://tech.ebu.ch

[30] Ghazi, I.: Digital Dividend and Spectrum Considerations. Regional Conference on Digital Switchover, ITU, Belgrad, November 2011.

[31] Statista: Anzahl der Mobilfunkanschlüsse in Deutschland von 1990 bis zum 3. Quartal 2012. [Online]: http://de.statista.com/statistik/daten/studie/3907/umfrage/mobilfunkanschluesse-in-deutschland/, on 19.12.2012

[32] Cisco: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2010 -2015. 2011, [Online]: http://newsroom.cisco.com/ekits/Cisco_VNI_Global_Mobile_Data_Traffic_Forecast_2010_2015.pdf

[33] Cisco: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2011 -2016. 2012, [Online]: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.pdf

[34] UMTS Forum Report: Mobile Traffic forecasts: 2010-2020. Report 44, January 2011.

[35] Analysys Mason: Wireless network traffic worldwide: forecasts and analysis 2012-2017. [Online]: http://www.analysysmason.com/Templates/Pages/KnowledgeCentreArticle1.aspx?id=12073

[36] Lüders, C.; Sörries, B.: Überlegungen zum Spektrumsbedarf zukünftiger LTE-Mobilfunknetze. Mobilkommunikation (ITG-FB 234), 2012.

[37] Report ITU-R M.2243: Assessment of the global mobile broadband deployments and forecasts for International Mobile Telecommunications. 2011.

[38] Report ITU-R M.2072: World mobile telecommunication market forecast. 2005.

[39] IST-4-027756 WINNER II: Spectrum requirement calculation tool for the future development of IMT-2000 and IMT-Advanced "Speculator" v. 2.26, 2007.

[40] Report ITU-R M.1768: Methodology for calculation of spectrum requirements for the future development of the terrestrial component of IMT-2000 and systems beyond IMT-2000. 2006

[41] Takagi, H.; Walke, B.H.: Spectrum Requirement Planning in Wireless Communications: Model and Methodology for IMT-Advanced. John Wiley & Sons, 2008.

[42] Report ITU-R M.2078: Estimated spectrum bandwidth requirements for the future development of IMT-2000 and IMT-Advanced. 2006

[43] Bundesnetzagentur: Szenarien zur künftigen Bereitstellung von Frequenzen in den Bereichen 900 MHz und 1800 MHz und in weiteren Frequenzbereichen (Szenenpapier Projekt 2016). BK1-11/003.

[44] European Commission: Document RSPG12-408: Final RSPG Opinion on Review of Spectrum Use. 6 February 2012.

[45] Real Wireless: 4G Capacity Gains Final Report. Figure 3-9 (Source FCC), January 2011.

[46] Real Wireless: 4G Capacity Gains Final Report. Figure 5-3 (Source NSN 3GPP Simulation), January 2011.

[47] 3GPP TR 36.912: Technical Specification Group Radio Access Network; Feasibility study for Further Advancements for E-UTRA (LTE-Advanced) Release 11. (Table 16.1.1- Table 16.1.4), V. 11.0.0, September 2012.

[48] Real Wireless: 4G Capacity Gains Final Report. Figure A-12 (source - trials), January 2011.

[49] Lüders, C.: Mobilfunksysteme. Vogel Business Media, ISBN 3-8023-1847-1

[50] Mishra, A. R.: Fundamentals of Cellular Network Planning and Optimisation. John Wiley & Sons Ltd. 2004.

[51] Wannstrom, J.: HSPA. [Online]: www.3gpp.org/HSPA

[52] Dahlman, E.; Parkvall, S.; Sköld, J.; Beming, P.: 3G Evolution HSPA and LTE for Mobile Broadband. Academic Press, 2007.

[53] Rysavy, P.: HSPA to LTE-Advanced 3GPP 3G Evolution to IMT-Advanced (4G). 2009, [Online]: www.3gamericas.org

[54] Weitzen, J.A.; Grosch, T.: Measuring Coverage Quality for Femtocell and Macrocell Broadband Data Services. In Proc. of IEEE International Conference on Microwaves, Communications, Antennas and Electronics Systems, COMCAS 2009.

[55] Field Trials of LTE with 4x4 MIMO. Ericsson review, no. 1, 2010, [Online]: http://www.ericsson.com/res/thecompany/docs/publications/ericsson_review/2010/ericssonreview_issue1_2010.pdf

[56] Small cells to make up almost 90% of all base stations by 2016. Press release, [Online]: http://www.smallcellforum.org/newsstory-small-cells-to-make-up-almost-90-percent-of-all-base-stations-by-2016

[57] 802.11ad-2012 - IEEE Approved Draft Standard for LAN - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications - Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band

[58] Mecklenbräuker, C.; Gaigg, P.; Ruhle, E.-O.; Reichl, W.; Malleck, H.; Lundborg, M.; et al. (2011): Frequenzverteilungsuntersuchung der möglichen Flexibilisierung im 900/1800 MHz Band. Wissenschaftliches Gutachten mit ökonomisch-frequenztechnsichem Schwerpunkt im Auftrag der Bundesnetzangtur für Elektrizität, Gas, Telekomunikation, Post und Eisenbahnwesen. (25 March 2011), [Online]: http://www.bundesnetzagentur.de/cae/servlet/contentblob/195666/publicationFile/10375/GutachtenFreqVertUntersuchgSBR_pdf.pdf

[59] 3GPP TR 25.814: Physical layer aspect for evolved Universal Terrestrial Radio Access (E-UTRA). P. 121, Table A.2.1.1-3, V7.1.0.

[60] 3GPP TR 36.814: Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects. P. 59, Table A.2.1.1-2 (antenna diagram)

[61] Kröhnert, S.; Kuhn, E.; Karsch, M.; Klingholz, R.: Die Zukunft der Dörfer. [Online]: http://www.berlin-institut.org/fileadmin/user_upload/Doerfer_2011/Die_Zukunft_der_Doerfer_Webversion.pdf

[62] http://www.statistik-portal.de/Statistik-Portal/de_jb01_jahrtab4.asp

[63] http://www.nt.tuwien.ac.at/about-us/staff/josep-colom-ikuno/lte-downlink-link-level-simulator/

[64] Federal Ministry of Economics and Technology "Mobile Media 2020" discussion paper of 12 November 2012

[65] Response of the Bitkom assocation to the Federal Ministry of Economics and Technology "Mobile Media 2020" discussion paper of 12 November 2012, 23.11.2012.

[66] Response of Telekom to the the Federal Ministry of Economics and Technology "Mobile Media 2020" discussion paper of 12 November 2012.

[67] Response of E-Plus to the Federal Ministry of Economics and Technology "Mobile Media 2020" discussion paper of 12 November 2012, 27.11.2012.

[68] Ofcom: TV white spaces. 22 November 2012, [Online]: http://stakeholders.ofcom.org.uk/binaries/consultations/whitespaces/summary/condoc.pdf

[69] Bundesanstalt für den Digitalfunk der Behörden und Organisationen mit Sicherheitsaufgaben (BDBOS): [Online]: www.bdbos.de, on 12 December 2012

[70] Fritsche, W.; Mayer, K.: Study of the mid- and longterm capacity requirements for wireless communication of German PPDR agencies – Final Report. IABG, 2011, FM49(11)Info3_IABG Study PPDR capacity requirements

[71] FCC Encyclopedia: 700 MHz Spectrum. [Online]: http://www.fcc.gov./encyclopedia/700-mhz-spectrum

[72] Peng, B.; Eden, M.; Priebe, S.; Jansen, T.; Häfen, J.; Kürner, T.: Feasibility Study of LTE for the Broadband Service Delivery in Professional Mobile Radio. In Proc. 9th International Symposium on Wireless Communication Systems, electronic version (5 pages), Paris, August 2012.

[73] J. Scott Marcus et. al.: PPDR Spectrum Harmonisation in Germany, Europe and Globally. WIK-Consult, Final Full Public Report of the Study for the German Federal Ministry of Economics and Technology (BMWi), FM49(11)Info2_WIK Report PPDR Spectrum Harmonisation

[74] FM49(12)032_Standardisation of Public Safety in 3GPP

[75] FM49(11)012_German PPDR frequency demands and needs-1

[76] Report from CG spectrum requirements, FM49(12)040

[77] FM49(11)008rev2_candidate frequency bands

[78] Switzerland, FM Radio Band II for PPDR, FM49(12)048

[79] Ericsson, Motorola Solutions, Airwave: A proposal for channeling arrangements of candidate bands considered by FM PT 38 and FM PT 49 and the corresponding options for PPDR broadband services ETSI proposed method for spectrum calculation. FM49(12)045

[80] Norway, Part of 694-790 MHz as a candidate band for BB PPDR, FM49(12)047

[81] France, Opportunities for BB PPDR in 400 MHz band, FM49(12)059

[82] Behörden Spiegel: Breitbandkommunikation – Die Zukunft des BOS-Digitalfunks. September 2011, P. 47

[83] Response of the association Privater Mobilfunk e. V. (PMev) to the Federal Ministry of Economic and Technology discussion paper "Mobile Media 2020" of 12 November 2012, 21.11.2012

[84] Bundesnetzagentur: Verwaltungsvorschriften für die Frequenzzuteilungen zur Nutzung von Funkanwendungen der Behörden und Organisationen mit Sicherheitsaufgaben. [Online]: http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/BNetzA/Sachgebiete/Telekommunikation/Regulierung/Frequenzordnung/VerwaltungsvorschriftenFuerFrequenzzuteilung/FunkanwendungenderBOSVVBOId9353pdf.pdf?__blob=publicationFile

[85] Press release from the Federal Constitutional Court of 17 August 2012, [Online]: http://www.bundesverfassungsgericht.de/pressemitteilungen/bvg12-063.html, on 18.12.2012

[86] http://www.oder-hochwasser.de/, on 18.12.2012

[87] GPO: Middle class tax relief and job creation act of 2012. [Online]:

http://www.gpo.gov/fdsys/pkg/PLAW-112publ96/pdf/PLAW-112publ96.pdf

[88] big-screen.de: [Online]: http://www.big-screen.de/deutsch/pages/news/hdtv-news/2012_08_11_9952_olympia-live-stream-zdf-freut-sich-ueber-rekordzahlen.php, on 10 October 2012

[89] Huschke, J.: Facilitating Convergence between Broadcasting and Mobile Services using LTE networks. Technical Symposium at ITU Telecom World (ITU WT), 2011.

[90] Schertz, A: Stromverbrauch von Rundfunk- und Mobilfunknetzen für die TV-Übertragung im Vergleich. FKT, P. 557-559, October 2012.

[91] TDF: B2M: using broadcast to deliver mobile multimedia efficiently, in EBU FORECAST`12 - Shaping a broadcast future. 2012.

[92] 3GPP TS 36.211: Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation. (Release 10), V10.2.0.

[93] NSN R1-074339: Transmission of P-BCH, P-SCH and S-SCH on dedicated MBMS carrier. 3GPP TSG-RAN WG1 Meeting, Shanghai, 8.-12. October 2007.

[94] Juretzek, F.: Point-to-Multipoint Overlay for LTE-Advanced. IFA TecWatch Talk, Berlin, 3. September 2012.

[95] ETSI EN 302 755: Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2). April 2012, V1.3.1, [Online]: http://www.etsi.org/deliver/etsi_en/302700_302799/302755/01.03.01_60/en_302755v010301p.pdf.

[96] Qi, J.; Neumann, P.; Reimers, U.: Dynamic Broadcast. Proceedings of 14th ITG Conference on Electronic Media Technology, Dortmund, S. 1-6, 2011.

[97] Neumann, P.; Qi, J.: Dynamic Broadcast. FKT 3/2012, P. 92-96, 2012.

[98] Palka, P.; Rother, D.: TV White Spaces – Ein Überblick. FKT 3/2012, P. 97-101.

[99] Qi, J; Reimers, U.: An Analytical Study of Energy Consumption in Dynamic Broadcast. IEEE International Conference on Consumer Electronics, January 2012

[100] Neumann, P.; Reimers, U.: Live and Time-Shifted Content Delivery for Dynamic Broadcast: Terminal Aspects. IEEE Transactions on Consumer Electronics, S. 53-59, February 2012