

PPDR Spectrum Harmonisation in Germany, Europe and Globally

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The opinions expressed are those of the study team,
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1 Introduction

This is the Final Public Report for a study of *Public Protection and Disaster Relief (PPDR) Spectrum Harmonisation in Germany, Europe and Globally* on behalf of the German Ministry of Economics and Technology. Our study takes as a crucial starting point a study of PPDR spectrum functional requirements that was conducted by IABG on behalf of the German Ministry of the Interior.¹

Our focus is over the medium to long term, roughly the period 2015 – 2025. The actions that we are evaluating typically take many years to put in place.

1.1 Motivation for the study

The German Ministry of Economics and Technology selected our team to conduct a scientific study of spectrum needs for public agencies with security responsibilities for Public Protection and Disaster Relief (PPDR). This study was motivated by a long-standing recognition of the need for spectrum, harmonised at European level, that would enable PPDR personnel to communicate using high speed broadband data, including in particular video.

New technology drives this interest in evolving PPDR communications. High speed data is of interest for a myriad of reasons, such as the ability to transmit building plans and other information in real time to fire fighters and other PPDR staff at the site of an incident. Cameras mounted on helmets or on unmanned drone vehicles offer the prospect of better informing decision-makers at headquarters, and doing so without needless risk to the lives of PPDR front line workers.²

Existing TETRA/Tetrapol harmonised allocations and technology are suitable for narrowband data, and technical specifications have been extended to enable wideband data transmission,³ but existing allocations and technology are felt by most experts to be inadequate for emerging broadband data and video needs. Regrettably, no consensus has emerged at European or global level as to how much spectrum should be allocated, or where, or how, largely because the requirements have not been rigorously studied or quantified.

Individual countries could conceivably meet their individual needs with spectrum allocations at national level; however, most experts and most stakeholders think that doing so would be fundamentally wrong-headed. Our findings in this study support their belief that a harmonised spectrum allocation approach should be preferred. There are

¹ Fritsche, Wolfgang/Mayer, Karl (20 Mai 2010): Studie zum mittel und langfristigen Kapazitätsbedarf der BOS in der drahtlosen Kommunikation, iABG.

² Ibid.

³ In the form of TETRA Enhanced Data Services (TEDS).

quite substantial synergies to be gained with an approach that is harmonised at European level, if not worldwide, as explained further in Section 1.2 later in this Introduction.

Germany, which has a substantial fraction of the European Union's PPDR staff, is seeking to work with other European stakeholders to ensure that the problem is at last solved in a way that meets the needs of all concerned.

1.2 The rationale for harmonisation at European level

This study is being conducted on behalf of the German Government, but it focuses on problems that are by no means limited to Germany; moreover, the German Government understands fully that it is unlikely that an efficient solution can be limited to Germany.

It is increasingly recognised that natural disasters or terrorist incidents will not necessarily follow lines arbitrarily drawn on a map. The mid-2010 flooding on the Polish-German border and elsewhere provided a recent reminder of this, as did the Iceland volcano earlier in 2010. European PPDR personnel must have the ability to interoperate with their counterparts in neighbouring countries, which would tend to imply that their equipment must operate in mutually agreed spectrum bands, and pursuant to mutually agreed technical specifications.

PPDR forces themselves indicate an increasing need for cross-border cooperation for day to day matters, not just for crises. Moreover, they recognise that if interoperable PPDR communications are not routinely used for everyday matters, it is unlikely that they would interoperate correctly when needed for a crisis.

The need for spectrum bands harmonised at European level is motivated by a number of additional considerations as well. As explained more fully in Section 5.6.2.5.1, there are three advantages that one would normally hope for with any harmonisation of spectrum: (1) economies of scale, (2) greater opportunities for coordinated action, and (3) the ability of equipment to roam across borders. All of these are of great potential importance in the case of PPDR spectrum harmonisation.

- Economies of scale and scope can reduce unit costs of development and production of equipment to meet PPDR communication needs;
- Enhanced ability for multiple countries to respond to catastrophes that impact them jointly can help to save lives and protect property; and
- Enhanced ability of one country to lend assistance to another again in the event of a natural disaster or terrorist act has obvious advantages in terms of safety of life and protection of property.

The benefits and costs of harmonisation are addressed in Sections 5.6.2.5.1 and 5.6.2.5.2, respectively, and are a major focus of the Germany-specific impact assessment presented in section 5.3.

1.3 What is “Europe”?

In speaking of harmonisation at European level, one cannot avoid considering what constitutes “Europe”. Europe has many different meanings, depending on context. For this study, one might consider (1) the current Member States of the European Union, (2) an extended view of the European Union, including EFTA countries (Norway, Iceland, Liechtenstein, Switzerland, and potential future access states); (3) the members of NATO; or (4) the members of the CEPT. These memberships overlap to a considerable degree, but they also differ in important ways.

For purposes of this study, we felt that it was not helpful to draw an overly sharp line on the boundaries of Europe. The interests of our client, the German government, appear to be best served by achieving a harmonised solution on the broadest possible basis. Countries that could be considered to be part of Europe writ large, under any of the previous definitions, are thus potentially of interest.

1.4 Our findings and recommendations

Our findings and recommendations appear in Section 6. Our key findings are:

- Assuming that one of the technologies recognised by the ITU as a future IMT-Advanced standard (presently there are two candidate technologies, LTE Advanced and Mobile WiMAX) is deployed, minimum spectrum requirements below 1 GHz for Germany are estimated to be 15 MHz uplink and 10 MHz downlink.
- The spectrum already identified for public safety use in the 5150 - 5250 MHz band, augmented if possible with spectrum from the largely unused 1452 - 1479.5 MHz band (currently intended for T-DAB use), should be adequate to address capacity “hot spots” arising from major events or incidents in Germany. Existing 802.11 based technology could be deployed in these bands, taking advantage of the higher power level permitted for public safety use in the 5150 - 5250 MHz band; alternatively, ad hoc mesh networks could be considered, or LTE picocells and repeaters.
- A minimum of 15 MHz (unpaired) somewhere between 1 and 5 GHz is estimated to be required on a harmonised European basis to support air to ground video links, with a further Germany-specific 7.5 MHz potentially required. Coordination with the military could be considered.

- We believe that wireless backhaul requirements for the wide area network can be met from existing microwave fixed link bands, possibly augmented by satellite in remote areas.

In broad outline, and based on the Germany-specific Impact Assessment that appears in Section 5 of this report, we believe that the best solution for Germany would be characterised by the following approach (which is identified as Option 4 in Section 5.5).

Option 4: Harmonised solution in one or more bands or tuning ranges below 1 GHz, plus one or more bands or tuning ranges above 1 GHz

- Lower bands or tuning ranges to meet requirements for coverage and building penetration
- Upper bands or tuning ranges to satisfy requirements for capacity / surges
- National augmentation of harmonised bands permitted within predefined tuning ranges
- Continued use of spectrum in 380-400 MHz range (not necessarily contiguous with the new bands) for TETRA/TETRAPOL

Our recommendations to the German Ministry of Economics and Technology appear in detail in Section 6.2. They are summarised below.

Recommendation 1. German policy should advocate a harmonised allocation with two bands below 1 GHz: one of 15 MHz (uplink) and one of 10 MHz (downlink).

Recommendation 2. Continued use of the and 5150 – 5250 MHz band for local PPDR, augmented if feasible by the use of the 1452 – 1479 MHz band.

Recommendation 3. Promote a 15 MHz (unpaired) harmonised air to ground allocation.

Recommendation 4. Take an integrated view toward the use of satellite, primarily for areas that are hard to reach with terrestrial networks.

Recommendation 5. Promote development of standards that enable seamless interoperability.

Recommendation 6. Promote full compliance with standards that seek to ensure interoperability.

Recommendation 7. Work with other European countries to seek consensus.

Recommendation 8. Be prepared to accept solutions that enable other countries to tailor the size of spectrum allocations to their individual circumstances, as long as full interoperability can be maintained.

Recommendation 9. Continue to work with CEPT/ECC, and particularly with PT 38, to achieve consensus.

Recommendation 10. Continue to work with the European Commission and with the Radio Spectrum Committee (RSC).

Recommendation 11. Engage with ETSI to ensure that it brings its work to a timely conclusion, while ensuring full interoperability, automatic recognition of country-specific bands, and the possibility of using standard protocol chipsets.

Recommendation 12. Continue to monitor international developments.

Recommendation 13. Work with the broadcasting community.

Recommendation 14. Work with NATO.

1.5 The study team and methodology

In the first half of 2010, the firm IABG conducted a separate consulting study under the auspices of the German Ministry of the Interior to determine the functional requirements of German agencies with PPDR responsibilities. Our project for the German Ministry of Economics and Technology sought to translate those functional requirements into more detailed spectrum requirements, to review what is known about PPDR spectrum requirements in other European countries and globally, and to make concrete recommendations based on those findings. In doing so, we needed to consider a range of technical options, including potential use of existing commercial services, and the possible use of shared spectrum versus exclusive use of spectrum bands.

Methodologically, we began by reviewing and absorbing the results of the IABG study with our counterparts at the Ministry of Economics and Technology, the Ministry of the Interior, and the consulting team at IABG. We then performed quantitative modelling to translate and further refine those results into detailed spectrum band requirements for the most likely frequency ranges.

In parallel, we used desk research, backed up with selective interviews, to refine our understanding of PPDR requirements in other countries. Inasmuch as the project effectively required us to take part in numerous fora in 2010 (including the ERO workshop in Mainz in March, the Ministry of the Interior workshop presenting the IABG results in June, ECC meetings in June and November, and Radio Spectrum Committee [RSC] meetings in July and December), we were able to solicit extensive stakeholder feedback without the need to schedule separate individual visits.

Armed with this input, we considered spectrum needs. We then formulated our Germany-specific assessment using impact assessment methodology, which is the European Commission's standard tool for considering costs and benefits.

The trade-offs between costs and benefits serve to bound the recommended size of the band. Further, some bands are more valuable for PPDR than others, because they can carry more information, or because unit costs for coverage would be lower, or because they are better able to penetrate buildings (of particular relevance to fire-fighters). Other

things being equal, our recommendations favour solutions where the societal socio-economic welfare surplus by which benefits exceed costs is greatest.

Members of our team have participated in two other highly relevant studies in recent years; thus, we started with a substantial knowledge base. One was “Optimising the Public Sector’s Use of the Radio Spectrum in the European Union”, a 2008 study for the European Commission; and the other was “Safety First: Reinvesting the Digital Dividend in Safeguarding Citizens”, for Motorola and EADS.

The policy and economics experts at WIK-Consult led the project. Aegis, a UK consultancy in spectrum engineering, analysed spectrum bands and modelled and quantified German spectrum requirements based on the output of the IABG study and their knowledge of current technology trends. Reinhard Wählen contributed in-depth expertise on PPDR spectrum usage and needs at German and European level. Prof. Dr. Peter Vary of the University of Aachen advised and guided the team as regards technical developments, and specifics of German allocations.

1.6 Structure of this report

Section 2 discusses the drivers of a need for additional broadband PPDR spectrum, together with potential ways of addressing those needs, including the use of commercial spectrum, the shared use of existing spectrum bands, and national versus harmonised exclusive spectrum band allocations. Section 3 contains our detailed assessment of German spectrum needs, drawing on the IABG study. Section 4 summarises studies of broadband PPDR spectrum needs in other countries. Section 5 discusses the options broadly available, and provides a recommendation in the format of an Impact Assessment. Finally, Section 6 summarises our findings and our recommendations to the German Ministry of Economics and Technology.

2 Additional spectrum for PPDR

This section discusses the overall needs and drivers for additional spectrum for PPDR in Germany and internationally. As such, it sets the stage for Section 2.4, which discusses on a broad brush basis the means of attempting to address those needs and requirements.

Section 2.1 discusses current narrowband and wideband spectrum allocations in Germany and throughout Europe. Section 2.2 summarises the technological changes that are re-shaping PPDR spectrum requirements. Section 2.3 discusses the emerging application data requirements for high speed data and video (including in support of drone vehicles) that tend to drive new spectrum requirements.

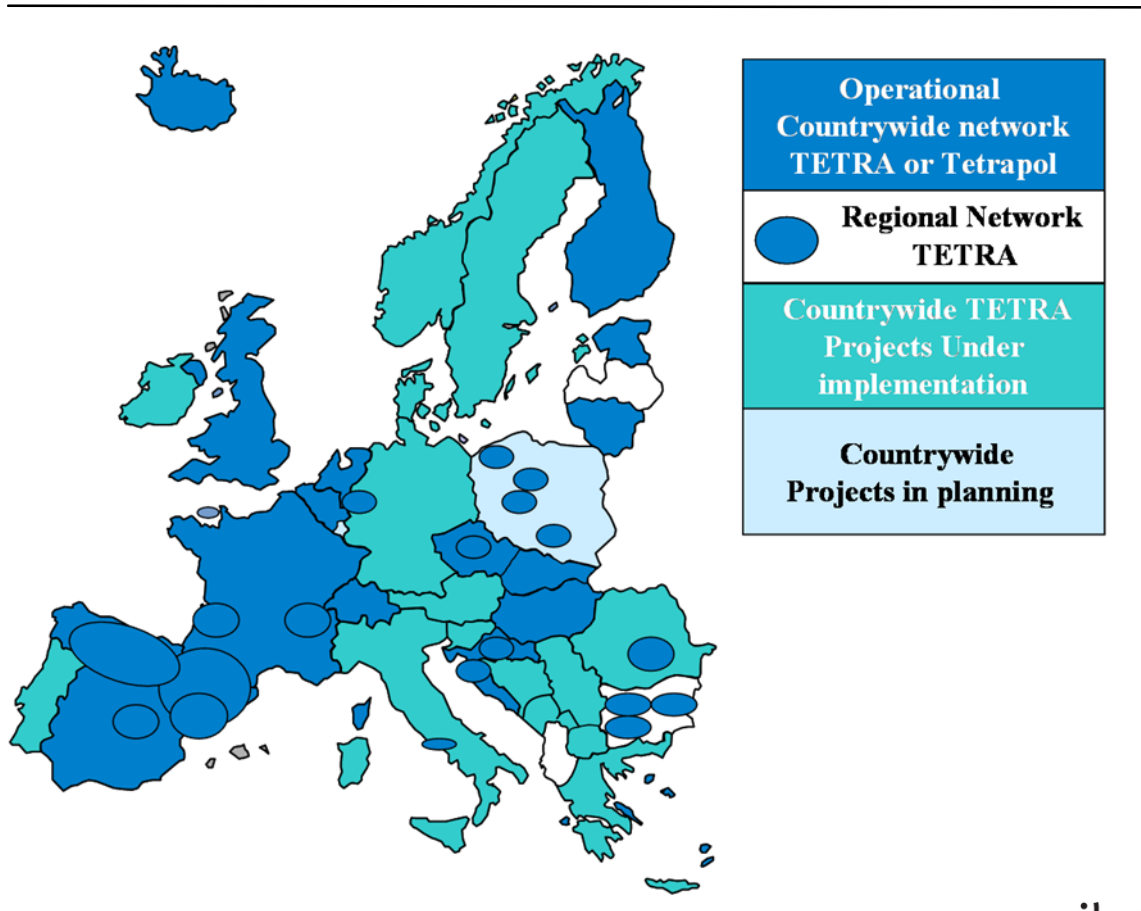
2.1 Current narrowband and wideband spectrum allocations

Public Safety organisations currently use a range of different communications networks to meet their operational needs. In Europe, the majority of public safety personnel now use dedicated networks to provide narrowband mobile communications⁴ using TETRA or Tetrapol technologies operating in the 380 - 400 MHz band⁵. This spectrum allocation is based on the harmonisation of spectrum for public safety that was put in place by the ECC in 1996. The map below provides an indication of those countries where narrowband networks had been deployed or were under implementation in 2008.

⁴ Additionally in many countries they also use existing commercial networks such as GPRS and 3G for some applications, and in some cases still use legacy analogue networks in other nationally allocated dedicated bands.

⁵ Former ERC/DEC/(96)01 defined the duplex bands 380 - 385 / 390 - 395 MHz.

Figure 2-1: European PSS Networks First Quarter 2008



Source: TETRA Association

Efforts to make additional spectrum available for wideband PPDR have been ongoing for many years, but have been effective to only a limited degree.

ECC Decision (ECC/DEC/(08)05) provides recommendations on the harmonisation of additional frequency bands for digital PPDR within the 380 - 470 MHz range. The Decision proposes that in addition to the spectrum already identified for narrowband services, spectrum should be made available in the 380 - 470 MHz band for wideband digital PPDR. An Annex to the Decision identifies the types of mobile system technologies that could be deployed.

There are significant barriers to the implementation of this decision. The same spectrum is also identified in ECC Decision (ECC/DEC/(04)06)for narrowband and wideband⁶

⁶ In this context, “wideband” systems typically deliver bit rates up to 384 kbps; higher bit rates are regarded as “broadband”.

digital land mobile (PMR/PAMR). In nearly 20 countries, the presence of CDMA 450 networks⁷ will impact on the availability of this spectrum for Public Safety organisations. Interest is also emerging in the commercial deployment of LTE technology in this band. It is worth noting that a 2007 review⁸ of the 400 MHz band could not identify a single harmonised band across 20 countries; and it was therefore necessary to consider a harmonised tuning range for the deployment of wideband mobile systems.

The 450 - 470 MHz band is also widely used in Europe by analogue private mobile radio services which in some cases (notably UK and Ireland) are not aligned with relevant CEPT recommendations and it seems unlikely that sufficient harmonised spectrum to support broadband mobile operation could be made available in a reasonable time frame.

For these reasons and others, our focus in this study has been on the medium to long term requirements for broadband (2015 to 2020), and not on possible shorter term requirements for a wideband extension within the tuning range of TETRA. We have found no indication that German needs would be well-served by an interim wideband expansion of spectrum, even leaving aside our doubts as to its practicality.

2.2 Technological trends and drivers

Recent years have seen increasingly rapid progress in the capability of technologies deployed in the commercial electronic communications sector, particularly with regard to over the air data rates and the spectrum efficiency that can be achieved. For example, when the first 3G technology standards were agreed in 1999 the maximum bit rate realisable over a 3G mobile network was 2 Mbps, though in practice most users experienced speeds in the range 64 - 384 kbps. By comparison the digital technology mainly deployed by the public safety sector (TETRA) could deliver up to 28 kbps. Many of today's 3G networks have been upgraded to the latest High Speed Packet Access (HSPA, HSPA+) technology and can theoretical peak bit rates of up to 21 Mbps (one user per cell only, best case channel, no error protection), with actual user bit rates of 1 Mbps or more in case of several users relatively commonplace in some networks in high density traffic areas, using a 5 MHz bandwidth channel. Work is progressing on an enhanced version of TETRA which will increase available bit rates with a theoretical maximum IP throughput of up to 500 kbps in a 150 kHz channel⁹; however there is an increasing gulf between the capabilities of commercial networks and dedicated PPDR networks, as the increasing demands to support broadband data require more

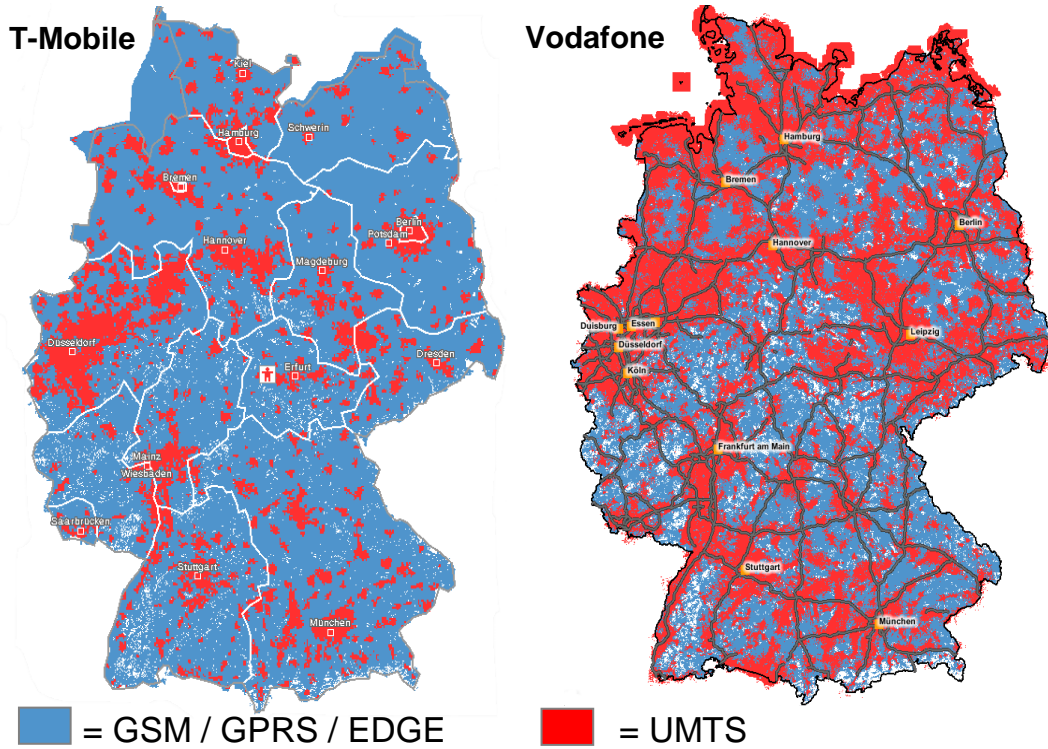
⁷ See <http://www.cdg.org/worldwide/index.asp> Countries listed are: Belarus, Bulgaria, Czech Republic, Denmark, Estonia, Germany, Hungary, Iceland, Ireland, Latvia, Moldova, Norway, Poland, Portugal, Romania, Russia, Serbia, Sweden and Ukraine.

⁸ ECC Report 102, "Public Protection and Disaster Relief Spectrum Requirements", January 2007.

⁹ Assumes 64-QAM modulation and coding rate of 1.

spectrally efficient technologies to be developed and implemented faster for the commercial sector.

Figure 2-2: UMTS coverage for the two best serving networks in Germany



Source: www.umts-netzabdeckung.de

In practice, many PPDR users make use of commercial 3G networks alongside their own dedicated networks; however, the coverage of the commercial networks is inferior (see Fig. 2-2, mainly because of commercial considerations in part because of the higher frequencies deployed and the corresponding smaller cell sizes). Moreover, networks are likely to suffer capacity constraints at times of high demand, which would tend to be the case in the aftermath of major public safety incidents. There could be significant benefit in extending the capabilities provided by commercial mobile broadband technologies such as HSPA, LTE, CDMA 2000 EV-DO and WiMAX to the public safety sector. Adopting such standards within dedicated PPDR spectrum would overcome the capacity limitations of commercial networks and also provide scope for interoperability with public networks which could facilitate inter-agency communication. Such an approach could also provide economies of scale with only the RF modules differing from standard commercial networks. Such technologies would be well suited to applications such as mobile CCTV.

2.3 Emerging needs for high speed data and video

Additional PPDR spectrum is needed for high speed data and video. Existing TETRA and Tetrapol systems have limited data capabilities. Video to headquarters is expected to play an increasing role in PPDR, not only in the form of helmet cameras, but also as a benefit of unmanned drones – on land, on water, and in the air.

Section 2.3.1 deals briefly with high speed data. Section 2.3.2 discusses the need for video in general, while section 2.3.3 discusses the more specialised demands of unmanned drone vehicles, ships and aircraft.

2.3.1 High speed data

High speed data will be just as important for PPDR as it has become in myriad pursuits – perhaps even more so. The ability to provide focused data on developing situations to PPDR workers in the field – building diagrams, for instance – is clear. The ability to relay comprehensive information back to headquarters is just as obvious. Just as broadband data has become essential to daily consumer activities, broadband data will become an increasingly routine aspect of PPDR activities, both on a day to day basis and in large scale emergencies. The IABG report documents numerous scenarios where this is the case.

2.3.2 Video

The first tests using video technology to improve operations and increase the security of the forces involved in PPDR are already in progress today. In light of a nationwide increase in violence against police forces in Germany, the first experiments are already under way with patrol cars equipped with video technology to record any incidents. There are clear advantages in being able to transfer this information to headquarters in real time, in order to keep command centre staff fully informed.

Video can also facilitate the identification of individuals and vehicles on location, so that the officials may be given additional instructions on site.

Live transfer from video links in helicopters already takes place in some scenarios, using nationally assigned frequencies. Helmet cameras can transmit live information to the control centre. All of this can serve to enhance command and control.

Fire fighters could be informed of the layout of a building by downloading images or video to a handheld device. Robots with high resolution cameras could investigate a building before human fire fighters are committed, to see if there are additional hazardous, flammable or explosive materials present.

2.3.3 Increasing use of drone vehicles and aircraft

There is likely to be increasing use of drone vehicles and aircraft over the next few years, mainly to obtain surveillance information without putting at risk the lives of the emergency services personnel. A drone vehicle might take the form of an unmarked car fitted with a number of concealed video cameras and a broadband wireless link. The vehicle's cameras will record all motion so as to enable the investigators to watch the footage in real time over the wireless link from the safety of a more distant location. A number of companies already market mobile CCTV systems that can relay real time video via 3G mobile networks; however, the coverage and resilience of these networks is unlikely to be sufficient for critical covert security operations, especially outside urban areas.

Unmanned aeronautical vehicles (UAVs) are increasingly deployed by the military, for example to provide remote surveillance over wide areas. Substantial bandwidth can be required, both to support surveillance video signals and the control and telemetry signals necessary to fly the UAV remotely. Whereas land mobile services require good non-line-of-sight performance, this may be less of an issue for UAVs, and there may thus be scope to use bands such as the existing 2300 - 2400 or 4400 - 5000 MHz military bands.

Agenda item 1.3 of the 2012 World Radio Conference addresses spectrum requirements and possible regulatory actions necessary to support the safe operation of UAVs. A draft report prepared by ITU Working Party 5B as part of the work on this agenda item identifies the following PPDR activities within the scope of UAVs:

- Coast line inspection, preventive border surveillance, drug control, anti-terrorism operations, strike events, search and rescue of people in distress, and national security.
- Public interest missions such as remote weather monitoring, avalanche prediction and control, hurricane monitoring, forest fire prevention and surveillance, insurance claims during and following disasters, and traffic surveillance are also included.

That report has attempted to estimate the additional spectrum that might be required to support all requirements across the United States, and concluded that the additional spectrum requirement could be as much as 34 MHz for terrestrial systems, and 56 MHz for satellite systems. Specific bands have not been identified at this stage.

2.4 Solving the need for PPDR spectrum

How should Germany go about solving the challenges put forward in this section in order to enable these new technologies to be deployed in support of PPDR

applications? How might the German government promote suitable supporting actions at European level and globally?

Section 2.4.1 discusses a number of alternative approaches to spectrum use, including (1) use of commercial services that already have spectrum assigned, (2) shared use with other applications, and (3) exclusive assignments, either in a single spectrum band or in multiple bands. Section 2.4.2 briefly reviews some key technological considerations. Section 2.4.3 concludes by considering, in general terms, the characteristics of one or more exclusive use bands to address emerging needs for broadband PPDR.

2.4.1 Alternative uses of spectrum

This section compares and contrasts different potential ways for PPDR to use spectrum.

2.4.1.1 Use of commercial services

This section assesses the relative costs and benefits of the use of commercial services for PPDR communications.

In a number of European countries, it is not unusual to supplement PPDR capabilities with the use of commercial services, especially for functions that are relatively less critical. Indeed, it is not unusual for PPDR workers to treat their mobile phones as an emergency backup to normal PPDR communications.

Trying to meet all PPDR requirements with commercial services, however, would have to overcome substantial challenges. Security forces' network operations are characterised by:

- A need for higher operational availability in particular in crisis situations;
- Full control over networks, enabling the unrestricted ability to adjust to any crisis situation;
- Coverage based on security needs, rather than public traffic flows;
- Higher security in main locations, and delay-free access to network resources;
- Extended running time in case of interruption of electricity supply;
- A stable network with the possibility of simultaneous data and voice operation; and
- The use of different technologies to meet different specific requirements, with central control of security and operations.

These requirements could not be fully met by public networks today, and they do not appear to be likely to be met by public networks any time soon. The requirements that stem from daily operations have necessitated specific consideration of the set-up and operational costs. Security networks are not operated on a profit-maximising basis, but rather as a response to security requirements.

Commercial mobile networks tend to be massively overloaded whenever a major event or disaster occurs. Thus, they are likely (in the absence of effective pre-emption) to be unavailable to PPDR precisely when they are most needed.

As a further example, commercial mobile networks tend to have battery back-up, but not generators. Base stations are often located in remote areas where the generators would be likely to be pilfered. Thus, commercial networks are likely to be off the air if power is disrupted for more than a few hours. This might be acceptable for commercial networks, but certainly not for PPDR networks.

PPDR forces will continue to attempt to use commercial networks when they can, or when PPDR communications are unavailable for whatever reason. This is all well and good, inasmuch as it reduces demand for PPDR-specific communications; however, it is unlikely to represent a comprehensive substitute for a dedicated, highly robust PPDR network.

2.4.1.2 Band-sharing with other applications

Spectrum band sharing is a key tool applied in spectrum management. It allows the coexistence of different technologies and radio communication services in the same band and in the same timeframe and enables the accommodation of new requirements.

In assessing the economic costs and benefits of a PPDR band shared with one or more other users, we need to consider any adverse impact that the sharing of the band would have (1) on the PPDR function itself, and (2) on the other user. The other user might or not be a public sector user (such as defence).

In Europe and throughout the world, band sharing is not unusual. Many forms are known, ranging from licence-exempt use as with WiFi, to sharing in different geographic areas (especially for directional signals). It is not unusual for military and civilian radars to operate in the same bands. In each instance, however, careful thought is required, and in many cases careful coordination as well.¹⁰

¹⁰ See John Burns, Paul Hansen, J. Scott Marcus, Michael Marcus, Philippa Marks, Frédéric Pujol, and Mark Redman, "Study on Legal, Economic, & Technical Aspects of 'Collective Use' of Spectrum in the European Community", a study on behalf of the European Commission, November 2006, available at:

http://europa.eu.int/information_society/policy/radio_spectrum/docs/workshop_collective_use/cus_rep_fin.pdf.

In a PPDR emergency, it is clear that PPDR must have sufficient (presumably unencumbered) access to its spectrum. This appears to imply the need for pre-emption, and that pre-emption must be extremely reliable.

There are examples of such systems. In a study of “Collective Use of Spectrum” for the European Commission¹¹ (in which WIK-Consult and Aegis took part), we noted that *Dynamic Frequency Selection (DFS)* represents a form of spectrum sharing with radars. At some level, DFS has been successful; however, it must also be noted that changes over time in the characteristics of the radar systems necessitated changes in the means of detecting (and avoiding) them, and that these changes were not easy to distribute to end-user equipment. Today, one could perhaps argue that *Software Defined Radio (SDR)* (e.g. ensuring that end-user equipment can be upgraded over the air link) provides a solution for such requirements.

As a cautionary note, we should point out that the United States attempted to provide a spectrum band pre-emptible by PPDR as part of its “D Block” auction. The US FCC attempted to “... award a nationwide 10 MHz commercial licence in the Upper 700 MHz ... Block to the winning bidder once it has entered into a Commission-approved Network Sharing Agreement ... with the [corporate entity established by the FCC to manage emergency services rights of access to the spectrum]. ... Under the Partnership, [emergency services] will have priority access to the commercial spectrum in times of emergency, and the commercial licensee will have pre-emptible, secondary access to the public safety broadband spectrum. Providing for shared infrastructure will help achieve significant cost efficiencies while maximizing public safety’s access to interoperable broadband spectrum.”¹²

Unfortunately, this approach failed. Private bidders did not have sufficient interest in the pre-emptible spectrum. Bids failed to reach the FCC’s reserve price. One possible interpretation is that the commercial value of a band that can be pre-empted by PPDR in an emergency is not very great; however, it must also be noted that the detailed arrangements for this band introduced enormous uncertainties for bidders that likely also reduced its effective commercial value.

2.4.1.3 Exclusive allocations of spectrum

The simplest mechanism for making spectrum available to PPDR use would be to make exclusive (or at least primary) allocations and assignments; however, this is also the most expensive approach. An exclusive assignment provides PPDR with full control over the resource; a primary allocation would mean that other secondary uses were permitted, but they would not be permitted to interfere with the primary PPDR use.

¹¹ Ibid.

¹² FCC, at <http://www.fcc.gov/pshs/public-safety-spectrum/700-MHz/safetyband.html>.

At the level of spectrum management, there are two primary costs associated with an exclusive allocation to PPDR: (1) the opportunity costs of not using the same band in some other way, and (2) the costs of clearing the band from whatever application currently is using it. We discuss these costs in our Impact Assessment in Section 5.

2.4.2 Technological requirements for broadband PPDR

The terms of reference for this study deal with spectrum needs, not specifically with technology; nonetheless, in order to model spectrum needs, we have found it necessary to make certain assumptions about the technology with which that spectrum will be used.

We have therefore assumed (without loss of generality) the use of a single overall intermediate to long distance technology employing some form of *orthogonal frequency-division multiplexing (OFDM)* within any new spectrum bands. We have used LTE characteristics for modelling purposes, but the results would not have been substantially different with another OFDM-based technology such as WiMAX.

LTE has been widely recognised as a plausible technological choice for broadband PPDR,¹³ but we do not wish to pre-judge the outcome of what is sure to be a complex technological debate. Moreover, it is not necessary to do so for the purposes of this study.

We have assumed that a different technology might be used for localised transmission, especially in the case of peak use (e.g. sporting events or concerts) or disasters (see Section 3.5.2). Candidates include some variant of IEEE 802.11 standards, or ad hoc mesh networking, or some form of LTE repeater and picocells.

We have separately considered wireless backhaul, as well as selective use of satellite where other solutions might not be suitable. These have technological considerations of their own.

Whatever technological standards are chosen, we would note that the following characteristics are highly desirable, if not absolutely essential:

- **Full interoperability:** Systems from different vendors, or procured for different European countries, should be able to interoperate at some predetermined level without modifications or special arrangements. Note that this is *not necessarily the case today* for TETRA or Tetrapol systems.

¹³ See for instance “NPSTC Votes To Endorse LTE Technology for Broadband Network”, 10 June 2009, at http://www.npstc.org/documents/Press_Release_NPSTC_Endorses_LTE_Standard_090610.pdf.

- **Economies of scale:** If technically feasible, equipment should be designed such that PPDR-specific capability is layered on top of an existing technology such as LTE or WiMAX. Doing so potentially reduces the time to market, enables the equipment to benefit from mass market economies of scale (e.g. in chipsets), and the possibility to interoperate flexibly with commercial networks (perhaps with reduced functionality).

2.4.3 Characteristics of a band or bands for exclusive use for broadband PPDR

If there were to be a set of exclusive allocations for broadband PPDR, should there be one band, or many? What can be said about the necessary characteristics of such a band or bands?

Several factors interact to determine the answer to this question. These include (1) the cost of achieving coverage over a country's full national territory, (2) the need for building penetration, (3) requirements for "burst" capacity for sporting events, concerts, and disasters, and (4) the performance characteristics of the equipment, especially as regards antenna design.

First, spectrum at frequencies of less than 1 GHz is ideal for achieving coverage. It is for this reason that spectrum in these bands is greatly sought after by mobile network operators, and by terrestrial broadcasters. These frequencies permit an ideal spacing between base stations, and thus enable coverage at lowest cost.

Second, although good building penetration is not needed for all PPDR applications, it is absolutely essential for some, notably including fire-fighting. For good building penetration, spectrum below 1 GHz is once again necessary due to physical constraints.

These two considerations both argue that broadband PPDR spectrum below 1 GHz is needed. Since it is impossible to predict the future, the spectrum should be sufficient to accommodate normal day to day needs without needless complexity (such as deploying relays).

At the same time, the opportunity cost of using spectrum below 1 GHz is *much* higher than that of other bands (see Section 6.1.3.3). This suggests that any allocation below 1 GHz should not be larger than is absolutely essential. Aside from economic considerations, a larger band below 1 GHz might simply not be realistically available; just as much of a concern, a larger band might not be available in all European countries, thus precluding a harmonised allocation.

The third consideration is the need for *burst capacity*. Spectrum needs for a concert or a major sporting event are large, but they are usually quite predictable. Disasters are not predictable, at least in terms of timing or location, but capacity requirements are certain

to exceed any reasonable day to day capacity in any case, so some kind of surge capacity is unavoidable. It is, however, both feasible and cost-effective to deploy relay units in all of these cases. Vehicle-mounted relay units with directional antennas would provide enhanced coverage and capacity where it is needed and make more efficient use of available spectrum resources than directly connecting individual users to the network. Since these relay units would be close to the scene, higher transmission frequencies could be used for local transmission from the relay to PPDR forces on the ground.

A fourth consideration relates to the performance limitations of radio equipment. For equipment operating at frequencies below 1 GHz, antenna efficiency considerations strongly suggest the use of a single band, within a tuning range of not more than 10% of the centre point of the band. Thus, a band or tuning range centred at 800 MHz, for example, could extend for 80 MHz, from 760 MHz to 840 MHz; however, a band or tuning range centred at for example 400 MHz could extend for just 40 MHz, thus from 380 MHz to 420 MHz.^{14 15}

Antenna design is somewhat less critical in higher frequency ranges due to the smaller physical size and greater efficiencies that can be achieved, but this does not overcome the inferior signal propagation at such frequencies which limits their utility for wide area coverage.

A single contiguous band (or a pair of sub-bands in the case of frequency division duplex (FDD) operation, which is more suitable for wide area broadband PPDR) for the sub-1 GHz spectrum will also tend to incur less unproductive overhead in terms of, for example, guard bands to reduce the risk of interference from or to adjacent spectrum bands, compared with a more fragmented allocation.

Taking all of these factors together, there seems to be a good argument for a single pair of sub-bands, no larger than necessary, below 1 GHz to accommodate needs for day to day coverage and for building penetration; and the possibility to augment this pair of bands with one or more bands above 1 GHz to accommodate the need for burst capacity for sporting events, concerts, and catastrophes. The localised nature of these high capacity requirements makes a time division duplex approach feasible, avoiding the need for higher frequency paired sub-bands.

¹⁴ We also wish to point out a statement in the memorandum “Public Safety frequency statement from 18 countries to the WG FM Workshop on Spectrum Harmonisation for Public Protection and Disaster Relief (PPDR) 11-12 March 2010 – Mainz (Germany)”: “.. we want ideally to be able to re-use the antenna sites we have today for the existing narrow-band systems, also for future wideband and broadband systems. Spectrum in the lower end around 400 MHz will have a positive impact on cost of deployment.” This is a legitimate factor to take into account, but only one of many.

¹⁵ Note also that at 400 MHz the percentage bandwidth may be lower for small form-factor devices like phone handsets or USB dongles, due to constraints on the physical antenna size

We return to these considerations in Section 5, where we explicitly consider whether a mix of bands below and above 1 GHz is preferable to a single, larger band below 1 GHz.

Bands might be somewhat different from country to country; bands might evolve over time. It seems to us that the possible use of multiple bands or tuning ranges argues for equipment that is sufficiently intelligent to automatically recognise the environment in which it finds itself. We return to this thought in Section 2.4.2.

3 PPDR spectrum needs in Germany

In this chapter, we build on the work undertaken in the IABG study, and make our own estimates of the spectrum requirements based on likely practical technical deployments. In doing so, we have modified some of the assumptions made in the IABG study in line with our own understanding of technology developments. We have also reflected the practical need to minimise spectrum requirements while still meeting the operational needs of the public safety sector.

3.1 The assessment conducted by IABG on behalf of the German BMI

The IABG study represents an excellent first cut at the problem, and contains a wealth of data, although as noted above we have found it appropriate to refine some of the assumptions in a number of areas. In the following sections we present a brief review of the IABG study, with a particular focus on the analytical framework used, the scenarios developed and the findings of the study with regard to data traffic and spectrum requirements.

3.1.1 Objective of the IABG study

The principal objective of the study was to estimate future demand for broadband wireless communications by the various German public safety agencies, and the implied requirement for radio spectrum. The main source of material for the analysis was a series of interviews undertaken with representatives of local and federal organisations covering the police, fire, medical and other public safety and security functions.

3.1.2 The analytical framework

IABG's approach was to define a number of specific operational requirements, and to estimate for each:

- the total data traffic requirement,
- how much of this traffic would be mission critical, and
- how much of this traffic could be considered redundant (e.g. due to availability of other means of transmission).

In this way a minimum data requirement was identified for each requirement. IABG then grouped together applications that were considered similar to one another and defined a data bandwidth to be associated with each of these groups of applications. The data bandwidth for each group of applications was further broken down according to the transmission platform that would be required (e.g. WLAN, LTE, satellite etc). For each

identified transmission platform, IABG then added together all of the individual data requirements arising from each application group and used this to define the total data requirement for each platform.

This process was carried out for three broad operational scenarios, namely:

- A. “Normal” operations, i.e. typical day-to-day operational scenarios;
- B. “Demonstrations and Major Events” with significantly higher communication needs, where the location and requirements are known in advance;
- C. “Natural Disasters and Major Incidents”, with significantly higher communication needs at very short notice where the location and requirements are not known in advance.

Within each of these three broad categories, six specific communication scenarios were identified, as summarised below:

1. **Data from the control centre to forces on the ground.** The core of this scenario is data transmission from a central control station to one or more personnel at the incident scene. The main data direction is the downlink. Applications vary by agency but typically include:
 - Fire Service: information regarding their location, e.g. evacuation routes, building plans, hydrant plans, instructions for handling hazardous materials, or information about the optimal way of cutting occupants out of vehicles;
 - Police: access to information databases on vehicles or people;
 - Medical Personnel: access to patient or medicine databases.
2. **Data from the forces on the ground back to the control centre.** This is essentially the reverse of the previous scenario and the main data direction is uplink. However, unlike scenario A these transmissions could involve high bandwidth applications such as video or high resolution photographs. Sensor data (e.g. monitoring a casualty’s vital signs) may also be conveyed, but will be less demanding in terms of bandwidth
3. **Communication between vehicles and the incident location.** Refers to communication between vehicles responding to an incident. May include transmission of video streams, voice or data communications to the vehicles.
4. **Communication between individuals on site.** This refers to “direct mode” communication between personnel at the incident scene, typically individual police officers, fire-fighters or paramedics. According to IABG, the number and density of the communication partners can be much higher than in Scenario 3,

although this seems questionable under normal operational conditions. IABG also assume there is no inter-agency communication required. Some data transfer requirements could be time critical, e.g. the transfer of data is very time critical, e.g. respiratory monitoring. Applications include text messaging, transfer of documents and potentially some video transmission.

5. **Use in tunnels, buildings or basements.** This scenario involves individuals within such confines that are communicating with individuals, vehicles or command posts outside the building. The existing analogue and TETRA voice networks are often not available in these situations. Applications could therefore include voice as well as pictures, sensor data and video transmissions.
6. **Access to information from the Internet or other external data sources.** Within each of these scenarios, specific applications were identified from the interviews for use in the bandwidth estimations.

3.1.3 Interview approach

IABG adopted a “guided interview” approach which appeared to involve asking a series of specific questions relating to users’ specific requirements. As a result there is some similarity in the requirements identified, with a particular focus on high bandwidth applications such as high resolution video.

3.1.4 Applications identified by Interviewees

The following table lists the applications identified by each of the twenty organisations that were interviewed by IABG and the corresponding scenarios (as summarised above) in which they would apply:

Organisation	Application	Scenarios	Ref
Federal Office for Goods Transport (BAG)	Broadband connection of mobile inspectors	A1, A2, A5 and A6	1.1
Bavarian mountain rescue	Voice	A1-A4, B1-B4 and C1-C4	2.1
	Simulcast with alarm	A1,A2,A5,B1,B2,B5, C1,C2 and C5	2.2
	Use of drones to explore	A3,B3 and C3.	2.3
	Redundant connection of refuges, relays and emergency call by radio to a network	A, B and C	2.4
Berlin Fire Department	Communication at the site	A3-A5,B3-B5 and C3-C5	3.1
	Alerting and Disposition	A1,A2,B1,B2,C1 and C2	3.2
	Control of traffic management systems to optimize the Infrastructure	A, B and C	3.3

Organisation	Application	Scenarios	Ref
	Transfer of patient to hospital	A6, B6, C6	3.4
	Information transmission from the control centre to use resources	A1, B1, and C1.	3.5
	Access to internal and external databases	A1, A2, A6, B1, B2, B6, C1, C2 and C6.	3.6
	Data transmission between NBC reconnaissance Weighing	A3 and C3.	3.7
	Infrastructure systems for the networking point of use with the control centre.	C1,C2, and C6	3.8
Fire Service Dortmund	Position detection and location transmission	A1-A4, B1-B4 and C1 - C4	4.1
	Communication of status messages	A2,A3,B2,B3,C2 and C3.	4.2
	Sensors on site	A3-A5, B3-B5 and C3 - C5	4.3
	Access to data services in the control room or on the Internet	A1,A2,A6,B1,B2,B6, C1,C2 and C6.	4.4
Bundeskriminalamt (BKA)	Data communications (video, audio, GPS, office communication)	A1-A6, B1-B6 and C1-C6	6.1
	Identification Commission (IDKO)	C1, C2, C4 and C6	6.2
Federal Police (BP)	Relationship between different control centres.	A1,A2,B1,B2,C1 and C2	7.1
	Connection of vehicles and fixed cameras, stationary and mobile control stations	A1,A2,A5,B1,B2,B5, C1,C5 and C2	7.2
	Voice as a complement / redundancy to TETRA	A1-A6, B1-B6 and C1 - C6	7.3
	Data transmission between people, vehicles and control centre	A1-A5, B1-B5 and C1-C5	7.4
	Video / image transmission and video conferencing	A1-A6, B1- B6 and C1 - C6	7.5
	Intranet or Internet	A1,A2,A5, A6,B1,B2, B5,B6,C1, C2,C5 and C6	7.6
	Direction Finding	A2, A5, B2 and B5	7.7
	Control / remote manipulation of drones	A1-A3,B1 - B3 and C1 - C3	7.8
	Underwater voice communication	A4, B4, and C4	7.9
	Networking devices on the man or the vehicle	A, B and C	7.10
German Fire Brigade (DFV)	Emergency vehicle access / MCU to control centre	A1, A2, C1 and C2	8.1
	Transmission of data on the location / building to the operational on site	A4, A5, C4 and C5	8.2
	Linking multiple control stations via radio	A and C	8.3

Organisation	Application	Scenarios	Ref
German Red Cross (DRK)	Data communication on site or with the control centre	A1-A3, A5, A6,B1-B3, B5, B6, C1- C3, C5 and C6	9.1
	Redundant wide area of country offices with the National Association	A1,A2, and A3	9.2
National Police Bayern	Video transmission from the helicopter to the control centre	A1, A2, B1, B2, C1 and C2	11.1
	Video transmission via DVB-T	A1,A2, A5, B1,B2, B5, C1,C2 and C5	11.2
	Connection of vehicles / people / locations to the central or the Police.	A1,A2,A5,B1,B2,B5, C1,C2 and C5	11.3
	Subdivision communications for different applications	A3, B3, and C3	11.4
	Network of relay stations with the headquarters	A, B and C	11.5
Brandenburg State Police	Mobile data connectivity to the patrol car to the headquarters	A1,A2,A5,B1,B2,B5, C1,C2 and C5	12.1
	Scenario data synchronization in the vicinity of a control centre	A1,A2,B1,B2,C1,and C2	12.2
	Video and image transfer between vehicles	A3, B3 and C3	12.3
National Police of North Rhine-Westphalia	Video transmission from the helicopter / plane to the central transfer point into the police network	A1, A2, B1, B2, C1 and C2	13.1
	Video transmission from a UAV to a ground vehicle	A3, B3, and C3	13.2
	Video transfer from fixed cameras at the central transfer point into the police network	A1,A2,A5,B1,B2,B5,C1,C2 and C5	13.3
	Transmission of sensor data to the central transfer point into the police network	A1,A2,A5,B1,B2,B5,C1,C2 and C5	13.4
	Motorized access strip (car and motorcycle)	A1,A2,A5,B1,B2,B5,C1,C2 and C5	13.5
	Mobile command posts, on land and water	A1,A2,A3,A5,B1,B2,B3,B5,C1, C2,C3 and C5	13.6
	Connection of non-motorized patrol officers (cyclists, Reiter, Fußstreife)	A1,A2,A5,B1,B2,B5,C1,C2 and C5	13.7
	Communication with a robot to defuse explosives	A3,A5, B3, B5,C3 and C5	13.8
MEK / SEK Niedersachsen	Fire Control System / Precision Rifle control system	A4,A5, B4, B5, C4 and C5	14.1
	Funkfernzündanlage	A3,A5,B3,B5, C3 and C5	14.2
	Video, audio and position data (GPS) on location and with the central	A2,A3,A4,A5,A6,B2,B3,B4,B5, B6,C2,C3, C4,C5 and C6	14.3

Organisation	Application	Scenarios	Ref
	Mobile Office: Access to Local Government Network and the Internet	A5,A6, B5, B6,C5, and C6	14.4
	Data transmission from the helicopter to a mobile	A3,A5, B3, B5,C3, and C5	14.5
SEK Baden-Württemberg	No need for wireless communications beyond analogue voice.	-	-
Fire and Civil Protection, District of Potsdam Mittelmark	Video image transfer to the operational commander	A3-A5,B3 - B5 and C3-C5.	16.1
	Data Applications	A1,A2,A6,B1,B2,B6,C1,C2 and C6	16.2
	Respiratory monitoring	A4, A5, C4, and C5	16.3
Technical Relief (THW)	Combination of placements and connectivity to the Internet	A1- A3, B1-B3 and C1-C3.	17.1
	Networking of installation	A3-A6,B3-B6 and C3-C6.	17.2
	Communication links in the area of operation abroad to the headquarters in Germany	A1,A2,A6,B1,B2,B6,C1,C2 and C6	17.3
Fire Department TU München	Data exchange with the control centre	A1,A2,A6,B1,B2,B6,C1,C2 and C6	18.1
	Data transmission on site	A3-A5,B3-B5, and C3-C5	18.2
	Connection of fire alarm systems to control centre	A1,A2 and A5	18.3
	Field Communication with the control centre	A1-A5,B1-B5, and C1-C5	18.4
BASF Fire Department	Data transmission between control centre and operational before	A1,A2,A6,C1, C2 and C6	19.1
	Networking of installation: transfer of data from location to the ELW	A3-A5 and C3-C5	19.2
	Transfer data from the control room at the ELW	A3 and C3	19.3
Customs	Data communication and consultation	A1 and A2	20.1
	Video and images	A1, A2 and A3	20.2

3.1.5 IABG findings

3.1.5.1 Data Traffic

The conclusions from the IABG study indicated a very large bandwidth requirement that the authors acknowledged would be unlikely to be satisfied by any practical wireless technology. The requirements were categorised according to the three broad scenarios previously identified (normal operations, major event and major incident), and to whether the requirement is mission critical and could not be delivered by any other

means (i.e. no redundancy). The example figures below, taken from the report, are for uplink capacity in a wide area cellular mobile network:

Table 3-1: IABG estimated total data requirements for uplink wide area network traffic

	Total demand (incl. non-mission and non-time critical)	Mission critical and time critical only	Mission critical and time critical only and no redundancy
Normal Operations	387 Mbps	223 Mbps	143 Mbps
Demonstrations and Major Event	651 Mbps	335 Mbps	255 Mbps
Natural Disasters and Major Incidents	621 Mbps	300 Mbps	220 Mbps

Although IABG have indicated geographic ranges for each application, it is not clear from the report how the above data rates would in practice be distributed across the network, i.e. how many cell sectors (and corresponding network capacity) would be available locally to serve the demand. We assume, however, that for the major event and major incident scenarios the requirements relate to a single event or incident and that in the worst case the requirement could relate to a single cell site.

3.1.5.2 Spectrum Requirement

In their report, IABG estimated that a realistic spectrum requirement for a wide area broadband mobile network for public safety would be 20 MHz in the downlink and 40 MHz in the uplink. In reaching this estimate, IABG have assumed a spectrum efficiency in excess of 10 bps/Hz for an LTE uplink (432 Mbps in 40 MHz of spectrum). This figure is based on trials carried out by Nokia Siemens Networks in 2007, with data rates multiplied by 4 to allow for anticipated improvements in the peak data rate for LTE Release 10 compared to LTE Release 8. However, while such high efficiency may be achievable under optimal conditions (e.g. a single user very close to the base station), the typical spectrum efficiency averaged across the network will be very much lower. According to the Third Generation Partnership Project (3GPP), which is developing the LTE Release 10 standards, the target average spectrum efficiency is 2 bps/Hz¹⁶, which would imply a spectrum requirement five times as great as that suggested by IABG, or 200 MHz for the uplink.

¹⁶ See "Proposal for Candidate Radio Interface Technologies for IMT- Advanced Based on LTE Release 10 and Beyond (LTE- Advanced), presentation by Takehiro Nakamura (3GPP TSG- RAN Chairman), October 2009 (www.3gpp.org/IMG/pdf/2009_10_3gpp_IMT.pdf).

The spectrum efficiency at the edge of the cell coverage area will be lower still – the lowest modulation / coding scheme option in LTE¹⁷ provides an aggregate data rate of up to 750 kbps in a 5 MHz channel, equivalent to a spectrum efficiency of 0.15 bps/Hz. As we will demonstrate later in this report, this variation in spectrum efficiency across the network coverage area is likely to be the dominant factor in determining the spectrum requirement for a public safety network.

3.1.5.3 Assumed Application Bandwidth Needs

In a few instances, we felt it necessary to re-visit IABG's assumptions as regards application bandwidth needs as we felt that the spectrum requirements, based on achievable spectrum efficiency, would not be realisable.

As a notable example, the assumption that many video streams need to be high definition drives bandwidth requirements that we would consider to be needlessly and impractically high. For many applications, such as observing what is happening with a crowd in real time, standard definition is probably adequate (bearing in mind as well that recording devices might record and store at greater resolution than that which is routinely transmitted under normal circumstances). Telemedicine likely requires high resolution, but it may not require a high frame rate, which again implies that it is neither necessary nor practical to transfer full high definition video at full speed from every camera. It should also be borne in mind that in many mobile video applications, the resolution is likely to be limited more by factors such as camera shake (for hand held cameras) or the small screen size of the viewing device than by the available bandwidth.

3.2 Our Methodology to Spectrum Demand Estimation

3.2.1 Introduction

Our approach to spectrum demand estimation is based on the scenarios identified by IABG, supplemented by other case studies that we have identified from other parts of the world. We have taken account of the likely performance capabilities of the technologies that we consider most likely to be deployed in future public safety networks and also revisited some of the assumptions about how specific communications requirements translate into data traffic demand and spectrum demand. As a first step, we attempted to develop a holistic view of public sector wireless communication needs, to identify the key elements that might be required.

¹⁷ according to 3GPP standard TS36.213, V9.2.0, Table 7.2.3-1, June 2010

3.2.2 Key Requirements for a Public Safety Wireless Communication Network

Public safety wireless communication differs markedly from commercial networks in that traffic demand is far less predictable, both geographically and temporally. Major incidents such as plane crashes or terrorist alerts are thankfully extremely rare but can happen anywhere and at any time. When such incidents do arise, communication needs are substantial and tend to be concentrated around a relatively small area (typically hundreds of square metres or less). It would be impractical, both in economic and engineering terms, to plan a conventional wireless network on the basis of such eventualities, since 99% or more of the capacity would never be used. A more effective approach is to plan a network to provide a basic minimum level of wireless connectivity at all locations that can be rapidly expanded on an ad-hoc basis to provide additional capacity to cater for unforeseen incidents.

One way in which this can be done is by adopting a multi-layer approach, using complementary frequency bands and technologies to provide the necessary coverage, capacity and responsiveness. As a starting point, we can define a number of essential requirements for a broadband wireless network, notably:

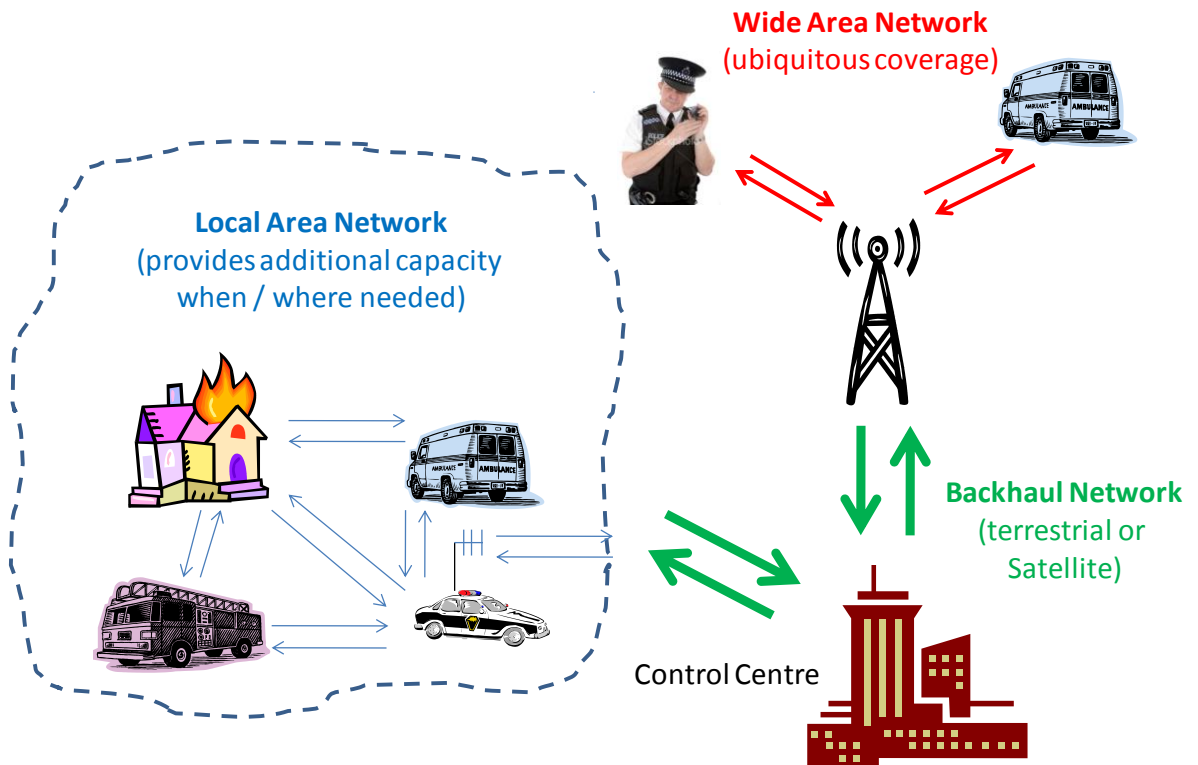
- Nationwide coverage with sufficient capacity to cater for routine, day-to-day data communication requirements (corresponding to IABG scenario A)
- Ability to extend coverage rapidly to challenging radio environments (tunnels, basements etc)
- Ability to expand available capacity rapidly within a local area anywhere (indoor or outdoor) within the network, to accommodate any foreseeable communication requirement arising from a major incident (IABG scenario C).

In addition to coping with unplanned major incidents, there will also be occasional requirements to cater for planned events which temporarily require a high level of network capacity (IABG scenario B). However, as such events are known in advance any necessary additional infrastructure can usually be planned well in advance and so presents less of a challenge in spectrum management terms.

3.2.3 Layered approach to coverage and capacity

To provide optimal coverage and capacity at minimal cost, a layered approach to network planning is required. There are essentially three layers: the local layer, the national layer and the backhaul layer, which are illustrated in Figure 3-1.

Figure 3-1: Layered Approach to Network Configuration



The backhaul layer connects the base stations in to the core network and will typically comprise fibre or microwave fixed links (though in some remote connections a satellite link may be required). The wide area network is designed to cater for day-to-day needs (IABG scenario A) and should be able to accommodate typical routine traffic levels wherever they arise in the network coverage area. Local area networks are configured either on a planned basis (to cater for events that are known in advance) or on an ad-hoc basis in response to major emergencies that require a high volume of wireless communications. They may also be used in normal operational scenarios where there is a significant amount of local on-site traffic

The advantage of this layered approach is that only the wide area network is generally required under normal operational conditions; however, where a major incident arises, a local area network can be rapidly deployed, with access points located in vehicles to provide both a backhaul link to the control centre and a hub for local on-site communication. A key challenge that this presents is how to provide backhaul to support ad-hoc local networks, especially in remote locations. This is considered further in Section 3.5.3.

3.2.4 Choice of Technology

It is unclear at this stage what technology standards might be deployed in future public safety wireless communication networks; however, in the commercial sector there is a clear migration path towards OFDM based technologies such as UMTS Long Term Evolution (LTE) and Mobile WiMAX for wide area mobile networks. These technologies provide improved resilience in difficult radio environments and improved spectrum efficiency compared to legacy technologies like TDMA and CDMA. We have therefore assumed in our estimation of spectrum requirements that a technology of this type will be deployed in the wide area layer.

These technologies could also be deployed in the local area layer, by using relays or temporary base stations, but an alternative would be to use technology based on the well-established 802.11 series of wireless local area network (WLAN) standards, which are already being used for public safety applications in some parts of the works (notably the US).

3.2.5 Frequency Duplexing Arrangements

The Duplex arrangement refers to how the uplink (terminal to network) and downlink (network to terminal) transmissions are separated. There are essentially two options: frequency division duplex (FDD) and time division duplex (TDD). FDD uses separate frequency channels for the uplink and downlink but allows each to transmit continuously. TDD uses the same frequency for uplink and downlink transmission, alternating rapidly between the two.

In FDD systems, the separation between uplink and downlink frequencies is generally fixed for any particular band, and is referred to as the duplex spacing. The need to find two paired frequencies with a sufficient duplex spacing to enable the two to be properly separated makes it more difficult to find suitable frequencies and provides less flexibility in that the uplink and downlink bands must be determined in advance and cannot easily be modified once systems are in operation.

TDD proponents claim that the technology can provide improved spectrum efficiency, particularly in situations where there is asymmetric traffic in the up and downlink. They also claim that TDD is better able to support dynamic link adaptation and smart antenna systems because the transmit and receive signals are on the same frequency. Whilst there is merit in these claims, there are two significant disadvantages inherent to existing TDD standards: (1) limited range (due to the necessary guard intervals) and (2) more demanding synchronisation requirements, both of which are likely to be more problematic in lower frequency bands than in higher frequencies due to the longer distances over which interference between systems might occur.

The range limitation of TDD systems relative to FDD is significant. For example, the suburban cell size in the 2.6 GHz band has been estimated to be 50% smaller for TDD¹⁸. For this reason, we do not consider TDD to be suitable for deployment in a wide area cellular network. The technology could however be deployed for localised applications, e.g. to provide additional capacity at an incident scene.

3.3 Estimating the traffic demand under normal operational scenarios

3.3.1 Introduction

As previously noted, we have revisited some of the assumptions used by IABG in estimating data traffic demand and have undertaken our own high level assessment of likely requirements, details of which are presented below. In addition to estimating the traffic associated with individual incidents, we have also used statistical data to estimate the potential number of simultaneous incidents taking place within the coverage area of a network base station, and the total spectrum that would be required to serve those incidents.

3.3.2 Typical Deployment Scenarios

To estimate the spectrum demand under routine day to day conditions, we have considered typical incidents that arise on a routine basis and must be dealt with by the public safety agencies. These include, for example:

- Highway accidents (primary respondent: police)
- Building fires (primary respondent: fire service)
- Medical emergencies: (primary respondent: ambulance / paramedic service)
- Criminal activity (primary respondent: police)

In some cases, more than one agency may be involved in the response, e.g. a serious highway accident may require the fire service to rescue vehicle occupants and paramedics to deal with casualties, whilst the police take overall charge of the scene. Each agency may have its own specific communication needs, but all of these must be able to operate concurrently.

For major events and incidents, we have considered the various scenarios identified by IABG and other example scenarios, notably a recent case study prepared by the New York City public safety authorities.

¹⁸ Source: "LTE and UMTS – OFDMA and SC-FDMA based radio access", Holma & Toscalà, John Wiley, 2009, p.387.

3.3.3 Comments on IABG scenarios

A number of scenarios were identified in the IABG study and referred to in section 3.1.2 above. These are reviewed briefly and commented on below.

Scenario 1: Data from the control centre to forces on the ground

For normal operational scenarios, data transfer requirements are likely to be modest (typically tens or hundreds of kilobytes per transmission); hence, this is unlikely to be a major driver of network capacity. For normal operations, we estimate the capacity requirement per incident to be approximately 500 kbps (downlink only).

Scenario 2: Data from the forces on the ground back to the control centre

A key factor here is the assumption about the number, resolution and duration of any video transmissions. IABG have suggested that there could be a need for multiple, high definition video uplinks even at day-to-day incidents; however, we consider it unlikely that more than one or two simultaneous video streams would be required, and we would question the need for high definition in typical emergency scenarios involving hand-held camera equipment. We estimate the capacity requirement per incident for normal operations at up to 1.2 Mbps in the downlink which would provide up to two reduced resolution or one standard resolution video streams, plus additional downlink data capacity. According to MPEG the following main classes of video resolutions have been defined:

- LDTV (Low Definition Television): 352x288 pixel
- SDTV (Standard Definition Television): 720x576 pixel
- HDTV (High Definition Television): 1080x720 or 1920x1080 pixel
- UHD TV (Ultra High Definition Television): 7680x4320 pixel

According to the MPEG4/H.264 video standard, a video transmission with an LDTV resolution of 352x288 requires a maximum bitrate of 768 kbps, which would be sufficient for small screens of handheld devices. The present terrestrial television (DVB-T with MPEG2) requires a bit rate of 3-3.5 Mbps per channel with an SDTV resolution of 720x576. With the MPEG4/H.264 standard, which will be used in the future DVB-T2 system, the bit rates per video stream can be reduced by a factor of more than two.

Scenario A3: Communication between vehicles and the incident location

Again the number, resolution and duration of any video transmissions will be key. It is unlikely that high definition would be needed for viewing on relatively small screen devices in vehicles. In some scenarios (e.g. where need to relay the same video feed to

a number of vehicles), it may be more effective to use a broadcast / multicast approach. Our estimated capacity requirement per incident for normal operations is 700 kbps in each direction, which would allow for one reduced definition video stream plus additional uplink and downlink data.

Scenario A4: Communication between individuals on site

The use of compact hand held devices means that only limited screen resolution is available. Consequently, relatively low video bit rates (a few hundred kbps) will often suffice, although there could be a need for some higher bandwidth video links, e.g. for viewing on laptop computers. The requirement lends itself to configuration of a local area ad-hoc network, which could make use of unpaired spectrum above or below 1 GHz. Our estimated capacity requirement per incident for normal operations, depending on the number of users involved, is up to 2 Mbps (both directions) – this would provide sufficient bandwidth for several standard definition video links between on-site users.

Scenario A5: use in tunnels / houses / basements

Extending coverage into these challenging environments ideally requires the use of lower frequencies (below 1 GHz) that are less affected by walls and other obstacles. A repeater station could be deployed, either using the licensed frequency band or a locally available “white space” frequency.¹⁹ Our estimated capacity requirement per incident under normal operation scenarios, depending on the number of users, is up to 2 Mbps (both directions) – but note that it is questionable whether such a multi-user scenario would fall under the category of “normal” operation.

Scenario A6: Access to information from the Internet or other external data sources

This is likely to be a more critical requirement at a major event or incident than under a normal operational scenario, due to the number of personnel involved and the likely duration of attendance. Under normal operational conditions, there is likely to be sufficient spare bandwidth available in the allowances made for the other five scenarios to support this application, much of which is unlikely to be mission and time critical.

3.3.4 Estimating the overall potential traffic requirement per incident

The following table summarises the estimated traffic requirements in the wide area and local area networks for normal operational scenarios based on our analysis in section 3.3.3 above. The “network” column indicates whether the traffic would need to be carried over the wide area or local area network, as illustrated in Figure 3-1 above.

¹⁹ I.e. a locally unused frequency in the UHF TV broadcast band (470 - 790 MHz).

Table 3-2: Summary of Capacity Requirements for Normal Operational Scenarios

Scenario	Downlink	Uplink	Network
A1 (Data from control centre to forces on the ground)	500 kbps	-	WAN
A2 (Data from forces on the ground back to control centre)	-	1,200 kbps	WAN
A3 (Communication between vehicles and incident location)	700 kbps	700 kbps	WAN
A4 (Communication between individuals on site)	2 Mbps	2 Mbps	LAN1
A5 (use in tunnels / houses / basements)	2 Mbps	2 Mbps	LAN2
A6 (access to internet and other data sources)	-	-	WAN

The total potential traffic requirement per incident for “normal” operations is therefore estimated to be:

- Wide Area Network: 1200 kbps downlink, 1900 kbps uplink
- Local Area Network (outdoor): 2 Mbps, up and downlink
- Local Area Network (indoor): 2 Mbps, up and downlink

3.4 Estimating the spectrum requirement for the wide area network under normal operational scenarios

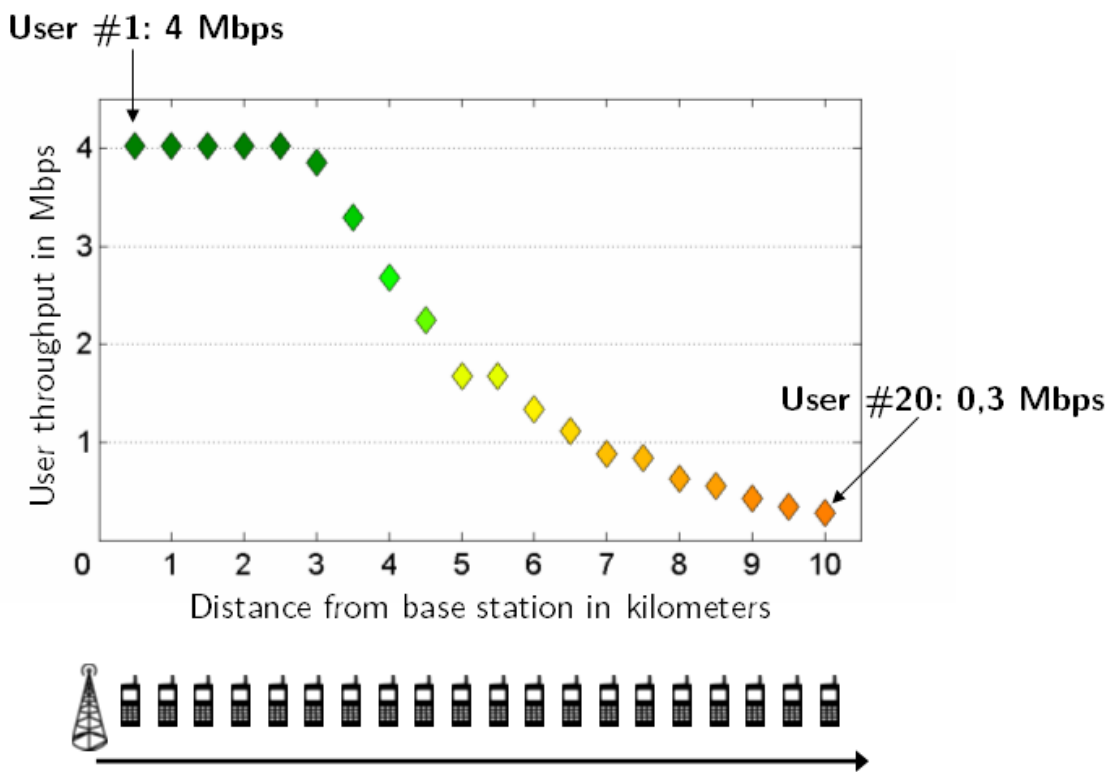
The spectrum required for the wide area network will depend on the assumed spectrum efficiency of the technology and the traffic throughput per cell at the busiest times. These two factors are considered in the following sections.

3.4.1 Spectrum Efficiency

Spectrum efficiency is a term used to describe the volume of data traffic in bits per second (bps) that can be carried per Hertz (Hz) of radio spectrum. Contemporary mobile networks deploying technologies such as HSPA, WiMAX or LTE use adaptive modulation and coding schemes to optimise spectrum efficiency according to the quality of the radio path available to each user terminal. The individual bit rates in LTE may vary between the centre of the cell and the cell edge by a factor of ten or more, as illustrated in Fig. 4.4.1.-1, for a 20 MHz LTE cell with active 20 users. The *average* spectral efficiency for HSPA+ is 1.5 bps/Hz and 1.7 bps/Hz for LTE with single antenna transmission, respectively. For a 2x2 MIMO system (Multiple Input Multiple Output, here: two transmit and two receive antennas), the *average* spectral efficiency increases to 2.5 bps/Hz. In contrast to that, a *single* active terminal that is located close to a base station will achieve a very high spectrum efficiency (up to 3 Mbps/MHz with existing

HSPA technology, potentially higher for LTE and LTE Advanced), whilst a terminal that is at the very edge of the cell coverage area will achieve a much lower efficiency (perhaps as low as tens of kbps/MHz currently, rising to almost 200 kbps/MHz in future LTE networks).²⁰

Figure 3-2: User throughput for 20 users in an LTE cell with a bandwidth 20 MHz²¹



In commercial networks, where there may be hundreds or thousands of users per cell, networks are planned to optimise the aggregate throughput for each cell, and in practice the data rates available to individual users will vary in line with the upper and lower spectrum efficiency bounds referred to above. Networks may aim to provide reasonable data rates to a sizeable proportion of users in a cell at any given time (e.g. 1 Mbps to 90% of users), but may have to accept that the remainder may have to settle for much lower rates.

²⁰ Note this would require access to an entire radio channel; the available bit rate could be substantially lower if there are several users sharing the channel.

²¹ Helge Lüders: Current and Evolved Physical Layer Concepts: Potentials and Limitations of Mobile Broadband Wireless Access, PhD RWTH Aachen University, 2010.

For an emergency service user, a much higher service availability is required because the consequences of communication failure are much worse than for commercial networks; hence, the network should be planned to provide an acceptable minimum bit rate even at the edge of the cell coverage area. The relatively small number of users of an emergency service network helps to achieve this objective in practice, since one of the main limitations on cell edge performance in a commercial network is interference from users in adjacent cells, and such interference will be much less likely in a network with far fewer users.

In our spectrum demand modelling, we have assumed that one of the incidents occurring within a cell will be towards the edge of the cell coverage area and the spectrum required for this incident is therefore based on the lowest spectrum efficiency value. We have set this value to **0.15 bps/Hz**, based on the minimum specified coding and modulation scheme in the LTE standards (QPSK modulation, 78/1024 coding rate).²² This is approximately twice the spectrum efficiency achieved by current TETRA networks (assuming a 12 cell re-use pattern) and does not take account of MIMO deployments which could theoretically improve the spectrum efficiency of LTE networks by 100% (2x2 MIMO) or more (2x4, 4x4).²³ We therefore consider this to be a conservative assumption for cell edge spectral efficiency, and appropriate for application to an emergency service network scenario.

3.4.2 Implications of bit rate limitation towards the edge of the cell

Adaptive modulation and coding is deployed in cellular networks to maximise the throughput per cell (by delivering higher bit rates where the radio path has sufficiently low loss to support this); however, as noted previously this presents a challenge for public safety networks, which have to be planned to ensure a sufficient data capacity at any location within the coverage area. This means either that there must be sufficient spectrum to support the required data traffic at a low spectrum efficiency, or that smaller cells must be deployed to achieve a higher spectrum efficiency throughout the network.

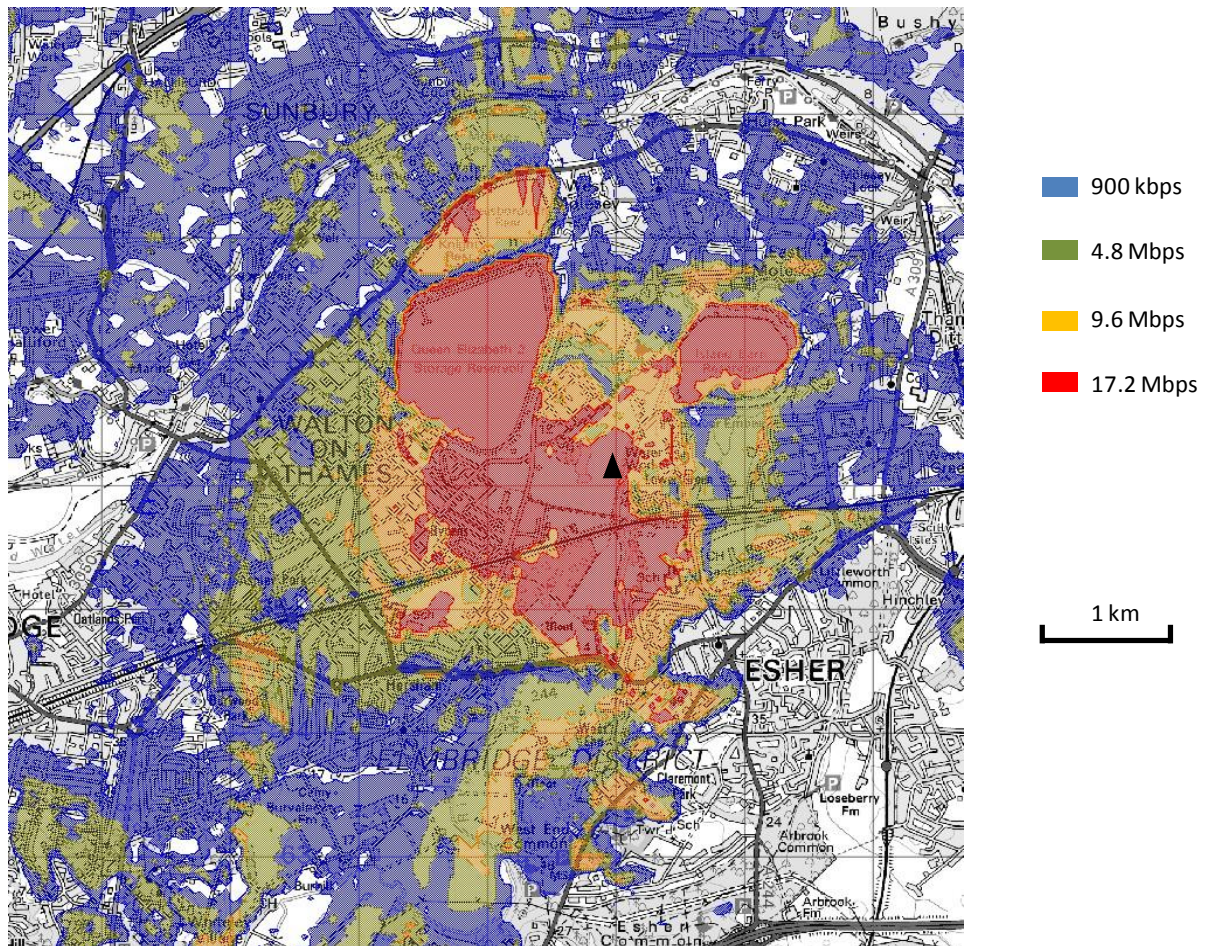
The implications of a higher required minimum bit rate are significant, as illustrated in Figure 3-3.²⁴

²² See table 7.2.3.1 in 3GPP specification 36.213, version 9.3.0 (September 2010).

²³ The 2:1 improvement over TETRA may appear modest; however, it should be noted that the average spectrum efficiency for LTE is much higher, whereas for TETRA there is no such improvement (as adaptive modulation and coding is not deployed).

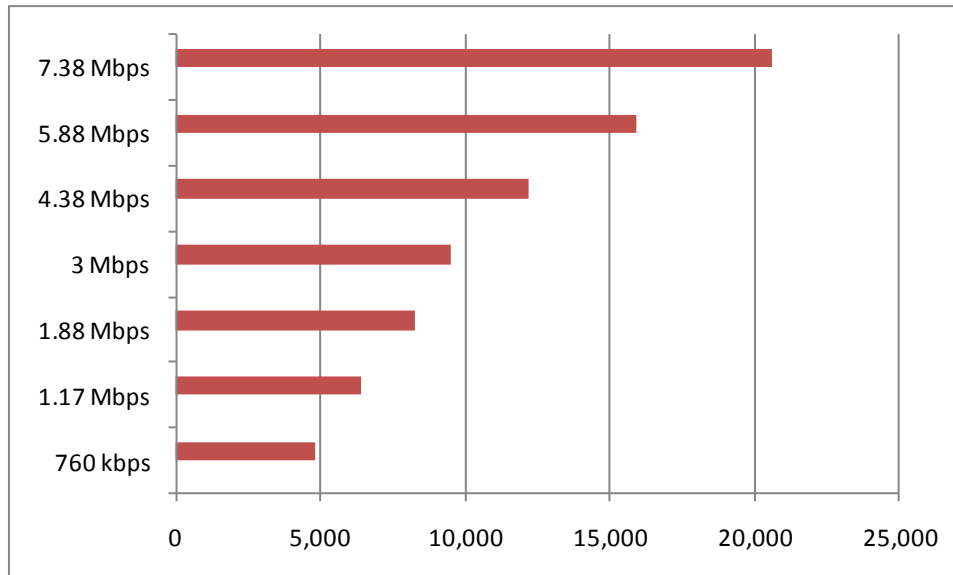
²⁴ Note that propagation modelling is based on the ITU P.1812 model with generic suburban clutter assumed and terrain data sourced from the UK Ordnance survey (50 metre resolution). Uplink outdoor coverage assumed, with a 3 dB interference margin to allow for inter-cell interference.

Figure 3-3: Coverage from a typical UK suburban cell site operating at 900 MHz, for different required LTE cell edge bit rates



It can be seen that coverage at the higher bit rates is less than half that available at the lowest bit rate, hence several times more sites would be required. The estimated impact of the cell edge bit rate on the number of sites likely to be required to provide national coverage in Germany is shown in Figure 3-4.

Figure 3-4: Number of cell sites to provide national coverage in Germany at 750 MHz, as a function of LTE cell edge bit rate (single user)



The link budget assumed in making this estimate appear in the Full Report for this study. All cells are assumed to be tri-sectorised and the COST-Hata propagation model has been used (urban, suburban or rural as appropriate).

Link budget parameters used in modelling

Tx Power dBm	23
Antenna gain dBi	0
Body loss dB	2
EIRP dBm	21
Rx Noise figure dB	3
kTBF dBm	-103.94
SINR dB	-2.56 to +8.45*
Receiver sensitivity dBm	-106.5 to -95.5*
Interference margin dB	3
Base station Feeder loss dB	2
BS Antenna gain dB	18
Fade Margin dB	9.05
Maximum Path Loss	131.45

*depending on modulation / coding scheme

3.4.3 Spectrum required to support a single incident near the cell edge

The spectrum requirement to provide for a single incident occurring at the cell edge can be estimated by dividing the total traffic per incident (as determined above) by the cell edge spectrum efficiency. This yields a minimum spectrum requirement of:

- **Downlink:** 1200 kbps / 0.15 = **8 MHz**)
- **Uplink:** 1900 kbps / 0.15 = **12.7 MHz**)

Note that this minimum spectrum requirement is substantially independent of country, assuming that similar assumptions about the data traffic per incident apply. Additional spectrum will however be required to support other incidents occurring simultaneously within the coverage area of the same cell, and this may vary by country depending on population density, incident statistics, and so on. This is considered Section 3.4.4.

3.4.4 Spectrum required to support additional incidents occurring within the same cell

3.4.4.1 Spectrum efficiency assumption for additional incidents

Any additional incidents taking place simultaneously within the same cell are assumed to be distributed randomly throughout the cell and we have therefore applied a higher spectrum efficiency figure, reflecting the average cell throughput, to those incidents. A value of **1.5 bps/Hz** has been assumed, which is 75% of the target spectrum efficiency for average cell throughput in LTE Release 10.

3.4.4.2 Estimating the total traffic throughput per cell

To estimate the total cell throughput and the spectrum bandwidth to support this, we have attempted to estimate how many incidents are likely to take place simultaneously within the coverage area of a single cell. To do this, it is first necessary to estimate the typical cell size for a network designed to provide the required level of coverage.

3.4.4.3 Estimating the cell sizes

The typical size of a cell depends on the frequency band, geotype (urban, suburban or rural) and the link budget. The latter parameter takes account of the effect of various parameters that affect the distance that a radio signal can cover. Once the link budget is defined, the maximum tolerable path loss can be determined and a radio propagation

planning model can be used to determine the corresponding maximum cell size for each geotype. Further information on LTE link budgets can be found in the literature.²⁵

Our assumed link budget parameters for an emergency service LTE network are discussed in Section 3.4.4.2. We have assumed that a minimum bit rate of 750 kbps per 5 MHz channel is required at the cell edge (corresponding to the total uplink capacity where the lowest modulation and coding scheme is used). This is consistent with our earlier cell edge spectrum efficiency assumption of 0.15 bps/Hz.

Applying the maximum path loss derived from the link budget (131.45 dB) to the COST-Hata propagation model yields the following estimated cell sizes for each geotype, depending on the frequency band:

Table 3-3: Cell coverage area (km²) as a function of frequency band (outdoor coverage based on above link budget)

	Urban	Suburban	Rural
750 MHz	4.8	16.6	180.1
1,450 MHz	1.8	7.9	98.6
2,350 MHz	0.6	3.3	49.0

Note the significant reduction in cell size as the frequency band increases. This results in a corresponding increase in the number of cells that would be required to provide national coverage, as illustrated in the table below:

Table 3-4: Estimated number of cells required to provide national (100% population) coverage in Germany as a function of frequency band

	Urban	Suburban	Rural	Total
750 MHz	237	3,024	1,633	4,894
1,450 MHz	634	6,381	2,984	9,999
2,350 MHz	1,869	15,254	6,009	23,127

It can be seen that deployment of a frequency above 1 GHz is likely to result in more than double the number of cell sites for a comparable level of coverage. We therefore assume that a frequency in the region of 750 MHz will be required for implementation of the wide area network, at least in rural and suburban areas (there are also substantial benefits from deployment of a lower frequency in urban areas, in terms of significantly better indoor coverage of buildings).

²⁵ See "LTE for UMTS – OFDMA and SC-FDMA based radio access", H. Holma and A. Toskala, page 222.

3.4.4.4 Estimating the number of simultaneous incidents occurring nationally

To estimate the number of incidents that might occur simultaneously within the coverage area of a single cell, we have used publicly available statistics (where these are not available for Germany we have scaled the data from countries where the information is available, using population as a scaling metric).

According to the Statistisches Bundesamt (www.destatis.de), in 2009 there were 310,806 traffic accidents involving injuries in Germany, of which 4,152 involved fatalities. Assuming that all accidents involving injuries require a police attendance, this equates to approximately 850 per day, or 35 per hour; however, accidents do not occur at a uniform rate throughout the day, but vary according to the level of traffic on the roads. According to UK government statistics, peak traffic levels are approximately twice the average level, and we assume this would also apply in Germany. We therefore assume that during the busiest hour of the day there would be approximately **70 highway accidents** being dealt with by the emergency services simultaneously across the country as a whole.

According to German Federal Police crime statistics²⁶, in 2008 there were 6.1 million recorded crimes in Germany. If all of these required a police presence that would equate to 16,712 incidents a day, or 696 per hour. Assuming that the peak rate of attendances is twice the average and it takes an average of one hour to deal with each incident, that equates to approximately 1,400 simultaneous **police crime responses** at the busiest time across Germany as a whole.

According to a study conducted by the Bundesamt für Straßenwesen, in 2004 there were 12.1 million emergency ambulance callouts in Germany, equivalent to an average of approximately 33,000 per day.²⁷ or 1,400 per hour. Assuming the peak rate of callouts is twice the average, that would imply up to 2,800 incidents per hour at the busiest times.

According to the German Fire Service Association²⁸, in 2007 there were 1,311,918 incidents that required the fire service to attend, involving 346 fatalities, This is equivalent to approximately 3,600 per day or 150 per hour. Assuming that the peak rate of incidents is twice the average, this implies up to 300 incidents involving the fire service across Germany in the busiest hour.

To summarise, the main traffic demand on a public safety network during normal operational scenarios is likely to be from police, fire and ambulance services, and the number of simultaneous incidents can be estimated as follows:

²⁶ Source: Police Crime Statistics 2008, produced by Federal Criminal Police Office, Section KI 12.

²⁷ Source: BASt M188, . www.bast.de/nn_42718/DE/Publikationen/Berichte/unterreihe-m/2007-2004/m188.html.

²⁸ www.dfv.org/statistik.html.

Table 3-5: Estimated simultaneous incidents occurring across Germany in the busy hour

Service	Simultaneous incidents (national)
Police (traffic accidents)	Up to 70
Police (crime response)	Up to 1,400
Ambulance service	Up to 2,800
Fire Service	Up to 300
Total	Up to 4,570

3.4.5 Estimating the distribution of incidents across the network

To estimate how these incidents might be distributed across national territory (and hence across the network, we have further subdivided the three geotypes used to estimate cell size (urban, suburban and rural) into eight population density categories. This is because spectrum demand tends to be driven by those areas within a particular geotype that have the highest population density – e.g. an area defined as rural for cell size purposes with 250 people per km² will require more spectrum per base station than an area defined as suburban with 350 people per km², despite the higher population density, because the assumed cell size in the suburban area (for coverage) is much smaller.

As there is no uniformly accepted standard for what constitutes urban, suburban and rural areas, we have applied our own assumptions for modelling purposes, which are indicated in the tables below. Data on population distribution has been derived from the publicly available *Gridded Population of the World (GPW)* database, version 3²⁹, which provides data on population density and distribution on an individual country basis. The relevant data used in the model for Germany and three other comparator countries is shown below. It is interesting to note that Germany has fewer people living in the most extreme rural or urban population density categories than the other countries considered, and more in the mid-range categories.

²⁹ GPWv3, generated by Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). 2005. *Gridded Population of the World Version 3 (GPWv3)*. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at <http://www.ciesin.columbia.edu>.

Table 3-6: Population Distribution by country

Population Density (PD) category	Sparse Rural	Medium Rural	Dense Rural	Sparse Suburban	Medium Suburban	Dense Suburban	Urban	Dense Urban
PD range	0-65	65-140	140-300	300-650	650-1400	1400-3000	3000-6500	>6500
Germany	1.89%	18.91%	28.19%	17.50%	13.87%	14.54%	5.10%	0.00%
Ireland	32.56%	8.11%	8.43%	9.50%	9.61%	15.54%	14.20%	2.05%
UK	4.37%	7.79%	13.92%	15.69%	21.80%	19.62%	12.66%	4.15%
USA	18.73%	7.66%	9.91%	13.69%	19.48%	18.07%	8.00%	4.46%

As a starting point, we have assumed that the geographic distribution of incidents follows population distribution. We have then applied a correction factor to allow for the difference between incident “hotspots” (i.e. areas with particularly high crime or traffic accident rates) and the average values. We have set this correction factor to 2, reflecting the ratio of the highest reported local crime rate in Germany to the average rate nationally.³⁰

Table 3-7: Estimated the number of simultaneously occurring incidents in the busiest hour by population density category (Germany)

Population Density	Traffic Accident	Crime Investigation	Ambulance Callout	Fire
Sparse Rural <65	2.6	52.9	105.8	11.3
Medium Rural 65-140	26.5	529.5	1059.0	113.5
Dense Rural 140-300	39.5	789.3	1578.6	169.1
Sparse Suburban 300-650	24.5	490.0	980.0	105.0
Med Suburban 650-1400	19.4	388.4	776.7	83.2
Dense Suburban 1400-3000	20.4	407.1	814.2	87.2
Urban 3000-6500	7.1	142.8	285.6	30.6

We then estimate the number of cells per population density category, by considering the distribution of land area by population density (again based on the GPW data):

³⁰ Source: national crime statistics.

Table 3-8: Land Area Distribution by country

Population Density (PD) category	Sparse Rural	Medium Rural	Dense Rural	Sparse Suburban	Medium Suburban	Dense Suburban	Urban	Dense Urban
PD range	0-65	65-140	140-300	300-650	650-1400	1400-3000	3000-6500	>6500
Germany	9.99%	42.67%	32.90%	9.06%	3.42%	1.64%	0.32%	0.00%
Ireland	89.25%	5.52%	2.57%	1.29%	0.66%	0.46%	0.23%	0.02%
UK	48.38%	18.58%	16.29%	8.44%	5.17%	2.26%	0.77%	0.11%
USA	89.55%	4.46%	2.64%	1.64%	1.08%	0.50%	0.11%	0.02%

The number of coverage cells in each population density category is estimated by dividing these values by the relevant cell size (urban, suburban or rural) from Table 3-3.

Based on this data, we have estimated the number of coverage cells that would be required in each population density category for a network operating at 750 MHz to be as shown in Table 3-9.

Table 3-9: Required cells by population density category

	Total	Sparse Rural	Medium Rural	Dense Rural	Sparse Suburban	Medium Suburban	Dense Suburban	Urban	Dense Urban
Germany	4,894	139	844	650	1,940	732	351	237	0
Ireland	510	342	21	10	54	28	19	33	3
UK	3,825	577	252	221	1,239	759	332	391	56
USA	75,136	24,172	4,822	2,854	19,366	12,753	5,904	4,455	810

The number of incidents per cell for each population density category is then calculated by dividing the number of incidents per category by the number of cells per category. We have assumed that the capacity and coverage of each cell will be optimised by deploying tri-sectorised base stations, hence the spectrum requirement will be determined by the number of concurrent incidents occurring within the area of a single cell sector.

The estimated number of incidents per cell and per sector are as shown in Table 3-10.

Table 3-10: Estimated concurrently occurring incidents per cell (during the busiest hour), Germany

Incidents per cell site by population category	Traffic Accident	Crime Investigation	Ambulance Callout	Fire	Total per cell	Total per sector (rounded up)
Sparse Rural <65	0.02	0.38	0.76	0.08	1.24	1
Medium Rural 65-140	0.03	0.63	1.26	0.13	2.05	1
Dense Rural 140-300	0.06	1.21	2.43	0.26	3.96	2
Sparse Suburban 300-650	0.01	0.25	0.51	0.05	0.82	1
Med Suburban 650-1400	0.03	0.53	1.06	0.11	1.73	1
Dense Suburban 1400-3000	0.06	1.16	2.32	0.25	3.79	2
Urban 3000-6500	0.03	0.60	1.20	0.13	1.96	1

3.4.6 Estimating the Spectrum Requirement to support total traffic throughput

The above analysis suggests that there are unlikely to more than two concurrent incidents occurring within the coverage area of a single cell sector. It is even more unlikely that this scenario would arise when one of the incidents is at the edge of the cell coverage area where the spectrum efficiency is lowest (0.15 bps/Hz). To estimate the spectrum requirement we have therefore assumed that there would be two concurrent incidents within the same cell sector area, that one of these would be at the cell edge and that the other would be at a location where the spectrum efficiency is at the projected average level for LTE, namely 1.5 bps/Hz.

The total estimated spectrum requirement is therefore the sum of the spectrum requirement already identified for a cell edge incident plus the additional spectrum that would be required to support a second incident within the same cell sector, assuming a spectrum efficiency for the latter of 1.5 bps/Hz. The total spectrum requirement in each direction is therefore estimated to be:

Table 3-11: Estimated total spectrum requirement (MHz) for public safety wide area network under normal operational scenarios

	Cell edge incident	Second incident in same cell sector	Total requirement
Uplink	12.7 MHz	1.27 MHz	14.0 MHz
Downlink	8.0 MHz	0.8 MHz	8.8 MHz

Assuming a channel bandwidth of at least 5 MHz (in line with current and most projected future LTE deployments, this implies a spectrum requirement of 15 MHz in the downlink and 10 MHz in the uplink. **We therefore conclude that the spectrum requirement for a wide area public safety broadband mobile network deploying LTE or similar technology under normal operational scenarios should not exceed 15 MHz in the uplink and 10 MHz in the downlink.**

3.4.7 Implications of increasing the minimum cell edge bit rate

We have seen that the spectrum requirement for the wide area network is essentially driven by the needs of a single incident at the edge of the cell. Increasing the cell edge bit rate will result in smaller cells (see section 3.4.2) and therefore require more cells to maintain the same coverage, but will also reduce the spectrum requirement at the edge of the cell. The following table shows the impact of increasing the cell edge bit rate to 1.17, 1.88 and 3.0 Mbps (based on the second, third and fourth lowest LTE modulation and coding schemes available) on the number of cells and the spectrum required to support an incident at the cell edge.

Table 3-12: Impact of increased minimum cell edge bit rate on uplink spectrum requirement

Cell Edge Bit Rate	750 kbps	1.17 Mbps	1.88 Mbps	3 Mbps
Cell coverage area km ² (suburban)	16.6	12.8	9.9	8.6
Cells required for national coverage	4,894	6,373	8,238	9,462
Cell edge spectrum efficiency (bps/Hz)	0.15	0.234	0.376	0.6
Spectrum required at cell edge	12.7	8.1	5.1	3.2
Spectrum required for additional incident in the same cell sector	1.27	1.27	1.27	1.27
Total spectrum ³¹	15	10	10	5

Our analysis suggests that investing in a further 1,569 sites would reduce the spectrum requirement by 5 MHz and that investing in a further 4,658 sites would reduce the spectrum requirement by a further 5 MHz. However, this result should be treated with caution as reducing the cell size would tend to increase inter-cell interference, which would partially offset the spectrum efficiency gain, increasing the required number of sites even further and casting doubt over the additional 5 MHz reduction for 3 Mbps. It is likely that in practice at least 10 MHz would be required regardless of the minimum bit rate chosen.

³¹ Rounded up to nearest 5 MHz.

A similar analysis of the downlink requirement suggests that increasing the minimum cell edge bit rate to 1.88 Mbps or more would reduce the spectrum requirement to 5 MHz, but the same caveat applies. Reducing the available spectrum in the wide area network would also have implications for dealing with major incidents, which are covered in the following section

3.5 Estimating the spectrum requirement for major events and incidents

3.5.1 Introduction

Major incidents differ from routine incidents in scale and complexity, but tend to occur very rarely. In some cases (e.g. natural disasters), communications may be further hampered due to infrastructure damage, and there is also likely to be a very high level of traffic on public telecommunication networks. There may also be a greater need for inter-agency communication at such incidents.

IABG estimated that the following bit rates would be required at a major incident, for mission critical applications where there is no redundancy:

- i) LTE Downlink: 183 Mbps
- ii) LTE Uplink: 220 Mbps
- iii) AdHoc Network: 140 Mbps

These very high data rates are largely driven by the assumed need for multiple high quality video streams, each requiring dedicated capacity of up to 4 Mbps. We believe that more realistic video bit rates would be in the order of 0.5 – 1 Mbps and that the total bit rates identified could therefore be reduced by up to a factor of 4, i.e.:

- i) LTE Downlink: 46 Mbps
- ii) LTE Uplink: 55 Mbps
- iii) AdHoc Network: 35 Mbps

A recent submission to the FCC by the New York City Fire and Police Departments included a scenario analysis for a hypothetical terrorist incident in the city, as part of a submission arguing for additional public safety spectrum to be made available. This “worst case” scenario involves a “dirty bomb” being exploded at the city’s main rail terminal, with 900 casualties, serious structural damage, radiation contamination and a number of fires.³² The total data throughput requirement for this scenario is estimated

³² See “700 MHz Broadband Public Safety Applications and Spectrum Requirements”, submission to FCC by NYC Fire and Police Departments and NYC Information Technology and Communications, February 2010 (www.psafirst.org/uploads/documents/NYC_Spectrum_Requirements-1.pdf).

to be 61 Mbps in the downlink and 17 Mbps in the uplink. It is assumed that all the traffic must be carried in one tri-sectorised LTE cell and would include both local area and wide area traffic based on our layered network approach.

It is our view that the NYC analysis may have underestimated the need for capacity in the uplink, and we believe that the IABG estimates, as corrected to take account of our assumed lower video bit rates, are probably more appropriate. We have therefore assumed that a major incident may require up to 50 Mbps of data capacity in both the uplink and downlink of the wide area network, with a further 50 Mbps to serve local communication needs.

Such high data rates present two challenges: (1) how to provide the necessary capacity in the local area network, and (2) how to backhaul the traffic to the wide area network. Clearly, if the major incident takes place towards the edge of a cell coverage area, no amount of spectrum would be sufficient to provide the necessary capacity.

3.5.2 Providing the required local capacity

The most effective way to provide capacity on a local basis is to configure an ad-hoc local area network. There are number of potential technical solutions to delivering such capacity, including:

- 802.11 (Wireless LAN)
- Mesh wireless network
- LTE repeater or picocell

Each of these options is considered below.

3.5.2.1 802.11 (Wireless LAN)

The 802.11 family of technical standards developed by the IEEE standards body underpins existing wireless network technologies commonly referred to as WiFi. The standards are primarily intended to operate in licence exempt spectrum in the 2.4 GHz and 5 GHz ranges, but in principle could be adapted to work in any available spectrum band so long as sufficient bandwidth is available (a minimum channel bandwidth of 20 MHz is required). The technology has evolved considerably over the last decade in terms of performance and WiFi systems can support many tens of Mbps, albeit over relatively small coverage areas (typically tens of metres in indoor environments).

The spectrum efficiency of the various Wi-Fi standards can be expressed in terms of the throughput available per MHz and is illustrated in the following table:

Table 3-13: Typical spectrum efficiency for Wi-Fi systems³³

Standard	Maximum usable throughput	RF bandwidth	Efficiency
802.11b	5 Mbps	20 MHz	0.25 bps/Hz
802.11g	22 Mbps	20 MHz	1.1 bps/Hz
802.11n	180 Mbps	40 MHz	4.5 bps/Hz

As with LTE, the coverage available depends on the required bit rate – the maximum throughput indicated here is available only over a very limited area. For example, Cisco’s Aironet 1250 series Access Point is specified to deliver up to 130 Mbps in a 20 MHz channel under ideal conditions, but this falls to as low as 6.5 Mbps at the edge of the coverage area. The throughput will fall even further (by 60% or more) if there are other systems using the same frequency in the same area.³⁴ The difference in link budget between the upper and lower throughput values is 13 dB, which would correspond to between a four and five fold reduction in range in an outdoor, open environment. The reduction in an indoor environment would be somewhat less, but from a much lower starting point, as illustrated in Table 3-14.³⁵

Table 3-14: Comparison of typical WiFi range at 5 GHz as a function of throughput (20 MHz channel, 802.11n, no MIMO assumed)

Throughput (bit rate)	Outdoor	Indoor
6.5 Mbps	250 m	70 m
65 Mbps	75 m	25 m

Deployment of MIMO could increase these bit rates by a factor of 3 - 4 times.

The range limitation of commercial WiFi systems largely arises from the power constraint applied (200 mW is assumed in the above estimates). For public safety use of the 4940 - 4990 MHz and 5150 - 5250 MHz bands (referred to hereafter as 5 GHz), a higher power level is permitted – 39 dBm or approximately 8 watts.³⁶ This would have the effect of extending the typical range of an access point as shown in Table 3-15.

³³ Source: Cisco product data.

³⁴ Based on measurements undertaken by Aegis Systems Ltd.

³⁵ Our range estimates assume free space propagation up to 5 metres (indoors) or 100 metres (outdoors) and a propagation exponent of 3.5 beyond.

³⁶ The higher limit applies to the access point only, however use of a higher gain antenna at the access point will enable a balanced uplink / downlink power budget to be realised, extending the range by a similar amount in both directions.

Table 3-15: Comparison of projected range of an 802.11n access point at 5 GHz as a function of throughput (20 MHz channel, no MIMO assumed), with the higher power permitted for public safety use

Throughput (bit rate)	Outdoor	Indoor
6.5 Mbps	690 m	190 m
65 Mbps	290 m	80 m

Our estimates suggest that use of the 5 GHz public safety bands using the latest 802.11n technology with MIMO technology would enable the estimated aggregate bit rates for a major incident scenario (150 Mbps total) to be met with a single 20 MHz channel, but that range would be limited particularly in indoor environments. This could be overcome by deploying multiple access points in a mesh configuration, as discussed below.

Access to dedicated spectrum in a lower frequency band such as 1452 - 1479 MHz would provide an optimal combination of coverage and capacity to cater for traffic hotspots at major incidents.

3.5.2.2 Ad-Hoc Mesh Wireless Network

A mesh network is essentially an interconnected network of multiple 802.11 access points, capable of rapid deployment and able to deliver high data throughput over a wide area. Such networks are already marketed in the US for deployment in the 4.9 GHz public safety band and can deliver data rates of up to 54 Mbps in a 20 MHz radio channel using current 802.11g technology.³⁷ Mesh networks can provide additional capacity at known demand hot spots, e.g. to support fixed video surveillance cameras or can be pre-installed to cater for planned major events, demonstrations, and the like. For disasters and major incidents, the networks are designed to provide rapid deployment and automatic configuration using mobile (typically vehicle mounted) access points. A helpful introduction to Wireless Mesh Networks can be found in a white paper produced by equipment vendor BelAir systems, one of a number of companies supplying such equipment to the US public safety community.³⁸

The disadvantage of the mesh approach is that it relies on deployment of potentially large numbers of access points if the incident spreads over a wide area, which may be problematic if there are areas that are inaccessible (e.g. due to fire or radiation leakage).

³⁷ See, for example, Proxim Wireless ORiNOCO® Public Safety Wi-Fi Mesh product (www.proxim.com/downloads/products/wifi_mesh_ps/ds_0806_ori4900wifi_ushr.pdf).

³⁸ Wireless Mesh Networks for Public Safety, available at www.belairnetworks.com/resources/pdfs/WP_PublicSafety_BDMC00070-A01.pdf.

The number of access points required would depend on the size of the area to be covered, the required bit rate and the spectrum that is available. For optimal performance at least four carrier frequencies should be available, to minimise the risk of interference between access points – this should enable the full required 50 Mbps to be available over substantially the entire coverage area. By way of example, for an incident spread over 1 km², and assuming a 50% overlap in coverage area between access points (to minimise the risk of “dead spots” without coverage), full outdoor coverage could be provided by eight access points distributed across the area.

3.5.2.3 LTE Repeaters and Picocells

Our working assumption for the wide area public safety mobile broadband service is that it will deploy an OFDM-based technology such as LTE that is optimised for use in a cellular environment; however, the technology could just as well be deployed on a localised ad-hoc basis by using repeaters or temporary base stations to provide enhanced coverage and capacity at specific locations. This could provide a very effective way to cater for the high traffic demand at major incidents, since locating a temporary base station or repeater at the incident location would ensure that all users in the vicinity would benefit from the highest available throughput.

Vehicular repeaters have been used to enhance local coverage of narrow band public safety networks for many years. These repeaters generally require access to a spare frequency channel to avoid interference with the main cell site. Although LTE technology can accommodate single frequency re-use, it is likely that two separate LTE frequency channels would be required to provide optimal throughput both locally and back to the main cell site.

The cell radius (in km) as a function of the cell edge throughput for an LTE base station operating at 750 MHz in typical urban, suburban and rural areas is shown in Table 3-16. The corresponding range for a high power 802.11 system deployed in the 5 GHz band at a similar data rate is also shown for comparison.

Table 3-16: Comparison of LTE cell radius (km) as a function of cell edge bit rate (750 MHz)

Bit Rate	Urban		Suburban		Rural		802.11 (6.5 Mbps) ³⁹	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
900 kbps	0.71	1.57	1.33	2.92	4.4	9.6	-	-
5.7 Mbps	0.35	0.76	0.65	1.42	2.14	4.7	0.19	0.69
17 Mbps	0.13	0.28	0.24	0.55	0.8	1.8	-	-

It can be seen that the range advantage provided by LTE at 750 MHz is much greater in suburban and rural areas, although there is also a significant advantage in terms of indoor coverage in urban high clutter areas. It is likely that 802.11 is best deployed in a mesh configuration to provide optimal coverage and capacity, but where this is not feasible (e.g. because it is difficult to gain access to deploy mesh access points) a local LTE repeater station could be the most attractive option. Deployment of a single LTE repeater would also reduce the need for overlapping coverage from 802.11 access points – for the example cited above of an incident spread over 1 km², the LTE repeater would provide good coverage with 10 Mbps or more over the entire area and additional 802.11 access points would only be required at specific traffic hot spots.

The limited capacity of a single LTE carrier (17.2 Mbps uplink for a 5 MHz FDD channel even with the highest order modulation and coding) means that at least 2 x 15 MHz would be required to meet the estimated major incident data throughput requirement in full. Additional capacity could be realised by using MIMO techniques, but these are as yet unproven in the sort of challenging radio environments that a major disaster would present. A more robust approach would be to use high power 802.11 access points operating in the 4.9 / 5.2 GHz PPDR bands to provide outdoor coverage, and to use LTE to provide coverage to more challenging areas within buildings or other obstructed areas and towards the edge of the incident area. With such an approach, it is likely that one or at most two 5 MHz LTE channels would be required.

3.5.3 Backhaul requirements for major incidents

Whichever technology is chosen to provide the additional local capacity required at the incident, it will be necessary to get data traffic to and from the locality, e.g. to provide access to the Internet or other remote data sources and to maintain communications with the agency headquarters. For planned events, especially those that occur at

³⁹ Operational frequency of 5.2 GHz assumed for 802.11 network.

regular venues (e.g. sports stadia, concert halls), it will be possible to install additional backhaul capacity in the form of fibre or microwave links; however, in the case of a major incident, there may be no local infrastructure available. In such cases, there are essentially three options, namely:

- i) Use the existing wide area (LTE) network to provide backhaul capacity
- ii) Establish a temporary fixed link using UHF or microwave frequencies
- iii) Establish a satellite link

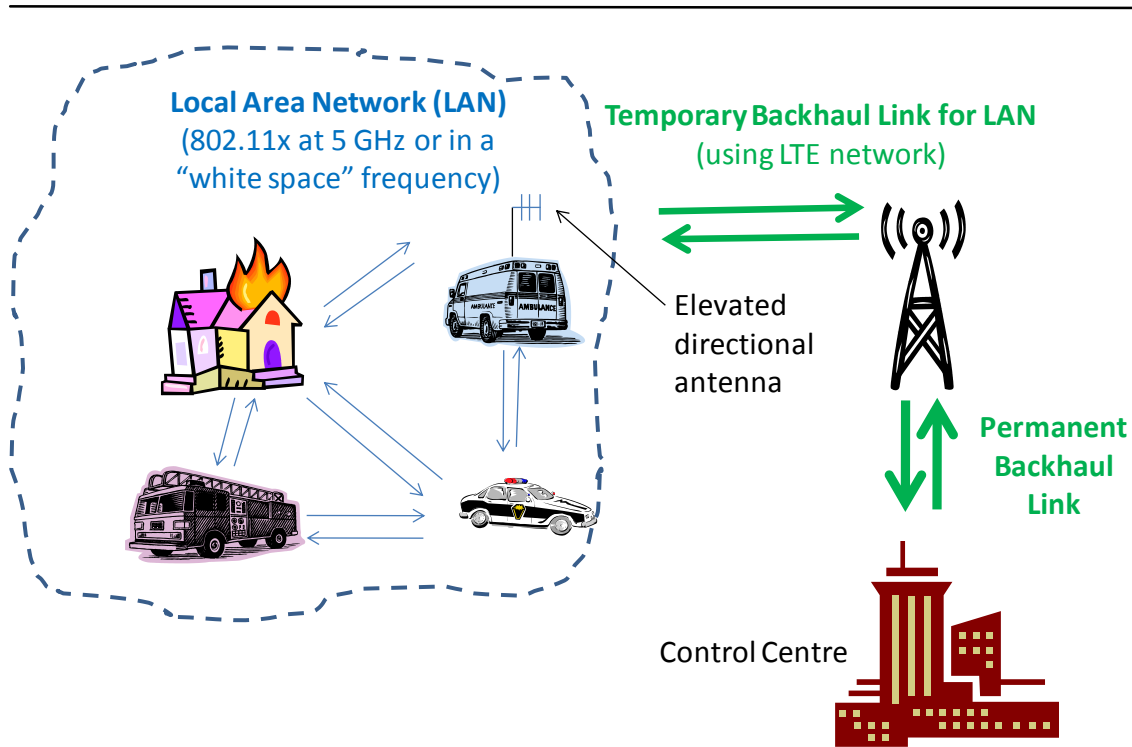
We consider each of these options in the following sections.

3.5.3.1 Using the existing wide area LTE network to provide emergency backhaul capacity

We have already noted that the available capacity of an LTE connection is very dependent on the quality of the radio link, and can vary between 900 kbps and over 17 Mbps in a 5 MHz channel. Further gains could be realised by deploying MIMO techniques. The difference in the link budget for these two extremes is approximately 26 dB and as can be seen from Table 3-16 above there is a 5:1 or greater difference in the cell size corresponding to these bit rates; however, in practice a similar or greater improvement in link budget can be realised by deploying a directional antenna pointed toward the nearest LTE cell site and elevating the antenna to be above the level of the surrounding terrain and clutter. Such an approach would enable the full maximum 17 Mbps per carrier capacity to be realised substantially anywhere within the coverage area of the main cell. Furthermore, MIMO deployment is likely to be much more effective in such a configuration, where both ends of the link are fixed for the duration of the incident, and there is much greater scope for optimal antenna spacing compared to a terminal device.

In practice, we believe this would enable our estimated 50 Mbps uplink and downlink traffic requirement to be within the capacity of the wide area spectrum identified for normal operational scenarios (i.e. 15 MHz uplink, 10 MHz downlink), so long as additional capacity is available to support local network requirements. We assume that the latter could be provided by configuring an ad-hoc 802.11 based network, as described in section 3.5.2.1 above (note that a mesh network may be required to provide adequate coverage at larger incidents). An alternative would be to deploy either 802.11 or LTE technology in a lower frequency band, perhaps using a locally available “white space” frequency in the UHF TV band or an alternative band such as 1452 - 1479 MHz if available.

Figure 3-5: Using the LTE network to provide a temporary backhaul link for an emergency WLAN



3.5.3.2 Using a temporary fixed microwave or UHF link to provide emergency backhaul

Temporary fixed links are widely used by broadcasters and others in the programme making and special events industry to cater for outside broadcasts. Typical bandwidths may be up to tens of MHz to support broadcast quality HDTV streams and frequency bands in the range 2 - 8 GHz are used, depending on the length of hop required and local frequency availability. It is of course necessary to have some means of connecting the remote end of the link to the core network: one way to do this may be to equip each base station in the network with an antenna that can be aligned with a particular location to meet a specific requirement. To work effectively, a line of sight path is ideally required; however, this could be achieved in most cases with an elevated vehicle-mounted antenna that could be positioned to avoid local clutter and terrain obstacles in a similar way to the LTE backhaul approach described previously. To provide the necessary capacity, we estimate that access to up to 2 x 15 MHz of spectrum would be required, ideally in the 1 - 3 GHz range to facilitate deployment in near-line of sight

situations. This would be sufficient to carry 50 Mbps in each direction, assuming 64QAM modulation is used.⁴⁰

A potentially more effective alternative may be to use UHF “white space” frequencies for temporary backhaul purposes. This would require knowledge of which TV frequencies are not in use locally, or deployment of sensing technology to determine which frequencies are free; however, in light of DVB-T receiver characteristics, the necessary frequency guard spaces have to be taken into account in order to keep adjacent channel interference below the required thresholds. Use of white space frequencies in this way would avoid the need to use LTE network capacity for backhaul and provide a more resilient link in situations where a clear line of sight along the link is not available. It could however require up to four 8 MHz TV channels in order to provide the necessary capacity in the up and downlink directions.

3.5.3.3 Using satellite links to provide emergency backhaul

In extremely remote locations (e.g. mountains) where it is not practical to deploy a terrestrial backhaul link, it may be necessary to use satellite. Power and dish size constraints tend to limit the available spectrum efficiency for portable satellite links, and rain attenuation limits the effectiveness of links in higher frequency bands (20 GHz and above) where the greatest capacity is available. Reserving large amounts of satellite bandwidth would be extremely expensive, as such bandwidth is in great demand for broadcasting and other commercial applications. It is therefore likely that satellite usage would be limited to provision of essential voice and narrow band communications rather than broadband.

3.5.3.4 Use of high altitude platforms to provide emergency backhaul

An alternative to satellite technology for providing coverage to remote areas may be to use an airborne platform (e.g. balloon or fixed aircraft) to act as a repeater between the area to be covered and the core network. Spectrum has been identified globally by the ITU in the 47.2 - 47.5 GHz and 47.9 - 48.2 GHz bands specifically for such applications. Although such frequencies are subject to severe rain attenuation, they should still provide good availability at low altitudes (up to a few thousand metres).

3.6 Requirements for Air to Ground Frequencies

In addition to the terrestrial network requirements discussed so far, public safety agencies also have regular requirements for airborne links, e.g. to support airborne surveillance applications. These typically involve a video stream being relayed from a

⁴⁰ According to Ofcom (UK) document Ofw 446 “Technical Frequency Assignment Criteria for Fixed Point-to-Point Radio Services with Digital Modulation”, a link conforming to ETSI spectrum efficiency class 4 deploying 64QAM modulation can carry 51 Mbps in a 15 MHz channel.

camera mounted on a helicopter to a monitoring station on the ground. The application is effectively a point to point link but because the helicopter is moving it is difficult to deploy very directional antennas so there is a risk of interference over a fairly wide area. Some countries have already set aside spectrum specifically for such use; for example, the UK and Ireland have each allocated approximately 20 MHz in the 3.5 GHz band, and we understand from the IABG study that Germany has allocated spectrum in the 2.3 GHz band.

At the moment, there is no harmonised frequency band for public safety air to ground applications in Europe. Given the nature of such applications, which can cover a very wide area and have potential benefit for cross-border operations, it would seem prudent to pursue such harmonisation as one of the goals for rationalising public safety spectrum in Europe.

The frequency requirement is dependent on the assumed demand for airborne video links, the estimated bandwidth per link, and the extent to which frequencies can be re-used. Current digital video surveillance systems⁴¹ typically deploy DVB-T technology but can operate in reduced channel widths, as low as 2.5 MHz or even 1.25 MHz. As surveillance applications may require relatively high resolution, a bit rate of several Mbps may be required, which would imply an RF bandwidth of at least 2.5 MHz. Frequency re-use for terrestrial DVB-T networks is generally between 4 and 6; in the case of air-ground use we assume that the higher value would apply (due to the wide area visibility of airborne platform), which would imply a minimum spectrum requirement of **15 MHz**.

Additional spectrum may be required locally, depending on individual national circumstances. For example, IABG has suggested that there could be simultaneous requirements in Germany for up to four video streams at a single incident, which would imply that up to 60 MHz could be required nationally (to allow for a 6:1 re-use and up to 4 x 2.5 MHz channels at each location); however, such a high level of demand is most unlikely. A more realistic estimate for Germany would probably be 22.5 MHz. This would address the base requirement of 15 MHz for normal operations, plus sufficient additional spectrum (3 x 2.5 MHz) to provide up to three additional video links at any one location at any given time in order to address exceptional scenarios where multiple links are required.

Although air to ground applications generally benefit from a line of sight path and do not therefore need to operate in the lowest frequency bands, the need for mobility probably rules out frequencies above 6 GHz, so we recommend spectrum in the range 1 - 5 GHz is deployed. Because of the potentially wide visibility of an airborne transmission and the likelihood that transmission may need to be received at an incident site, it is unlikely

⁴¹ See for example Cobham Surveillance COFDM - Video, Audio Telemetry and IP Products catalogue (www.cobham.com/media/28863/domo_product_catalogue.pdf).

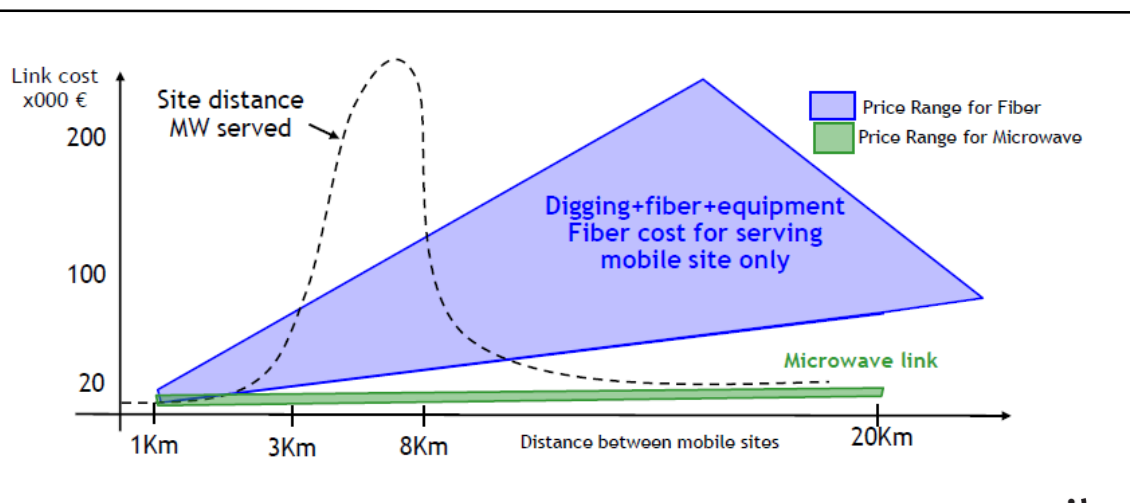
that air to ground applications could share spectrum with terrestrial public safety wireless systems.

3.7 Requirement for Backhaul Frequencies to support the Wide Area Network

Backhaul refers to the core network that interconnects the wide area network base stations and other external networks and users. The backhaul network must have sufficient capacity to handle the peak traffic that may be generated by each base station. In many cases it may be feasible to provide a fibre link to the base stations but in some cases where this is not practical it will be necessary to use a radio solution. Note that this requirement should not be confused with the temporary backhaul requirements for major incidents described previously.

As can be seen from the figure below microwave links tend to be cheaper compared to the installation of new fibre and more than 80% of commercial cell sites in Europe use microwave radio – it is expected therefore that there will be a significant demand for microwave radio to meet the network demands of the day to day operations.

Figure 3-6: Cost comparison of microwave radio and fibre for 3G networks



(Source: Alcatel Lucent)

3.7.1 Approaches to providing wireless backhaul

There is the potential, if LTE technology is deployed, to use in-band self-backhauling where physical resources are dynamically shared between self-backhauling and access traffic. In this scheme, a base station requires user equipment like transceiver capabilities as the backhaul traffic is transmitted / received from another base station in

a similar way to the radio access traffic is transmitted / received from a user terminal. This implies that a self-backhauled LTE base station should be able to transmit the backhaul traffic in SC-FDMA and receive it in OFDMA format, similar to the LTE user equipment uplink and downlink radio access modulation schemes; however, the inclusion of self-backhauling, as a layer 3⁴² solution, would most likely apply to LTE-Advanced where spectrum allocated might have carriers larger than 20 MHz, and thus is unlikely to be applicable to Public Safety networks.

The normal approach, to date, is to deploy out-of-band self-backhauling where the access and backhaul link operate on separate bands. There is a wide range of frequency bands that are available from 4 GHz up to the millimetre wave bands such as 38 GHz. Microwave radio links are now being sold with adaptive modulation which maximises the use of the available spectrum (bandwidth). The links are designed so that in periods of fading high priority traffic will still be supported at the required availability by using more robust modulation such as QPSK; however, when there is no fading or limited fading, the fade margin can be used to support lower priority traffic by moving to more efficient modulation such as 64 QAM.

3.7.2 Bandwidth Requirements

Traditional fixed point to point radio links were designed to deliver a required system availability taking into account the impact of propagation outages due to fading caused by rainfall or anomalous propagation (e.g. ducting). This means, for example, that a link designed for 99.995% availability would be unavailable for about 26 minutes a year. The use of adaptive modulation in more recent equipment allows the modulation deployed to vary according to the propagation conditions over the radio path, and thus maximises the use of the available bandwidth without increasing the transmitter power and interference environment.

The use of adaptive modulation maximises the use of the available bandwidth. It reduces the need for higher transmitter powers or shorter link lengths, whilst still meeting the required availability.

The other important consideration in defining the total bandwidth requirements to provide backhaul links is the ability to re-use the frequencies. In the millimetre bands, the potential for re-use of the same frequency is much higher than in the lower bands such as 4, 7.5 or 13 GHz due to the propagation characteristics of the bands; however, the achievable link lengths are significantly shorter as well.

It is likely that a mix of frequency bands will be required to support the link length and also capacity needs, but it is expected that there should be sufficient spectrum available in existing fixed link frequency bands. We do not therefore consider that exclusive spectrum will be required to support backhaul applications for public safety networks.

⁴² Layer 3 – wireless router (layer 3 relay) forwards IP packets on the network layer.

3.8 Summary of our findings on spectrum demand

In summary, we have identified the following minimum spectrum requirements to meet the needs of the public safety community for broadband mobile communications over the next decade, based on anticipated user needs and technology developments:

3.8.1 Spectrum to support Wide Area Mobile Broadband Communications

Assuming that one of the ITU recognised IMT-Advanced technologies such as LTE Advanced or Mobile WiMAX is deployed, we estimate that the minimum spectrum requirements will be:

- **Uplink: 15 MHz**
- **Downlink: 10 MHz**

In order to provide optimum coverage and to keep the required number of cells to a manageable level, a frequency below 1 GHz should be used. The dominant driver of spectrum demand in the wide area network is to cater for an incident that occurs at the edge of the cell coverage area, and the spectrum requirement is substantially unaffected by the presence of additional incidents elsewhere in the cell, because of the higher spectrum efficiency that exists away from the cell edge. Building a higher density network would increase the minimum cell edge efficiency and could reduce the spectrum requirement to 10 MHz and 5 MHz for the up and downlink directions, but this would require many more cell sites and would constrain the use of the wide area network to backhaul traffic from major incident scenes. We do not therefore recommend this option.

3.8.2 Spectrum to support Local Area Mobile Broadband Communications

Our analysis indicates that **spectrum in the 5150 - 5250 MHz band, which is already identified for public safety use, together with possible use of the 1452 - 1479 MHz band** is likely to be adequate to cater for most capacity “hot spots” arising from major events or incidents. Existing 802.11 based technology could be deployed in the 5150 - 5250 band, taking advantage of the higher power level permitted for public safety use. In some cases, it may be necessary to deploy multiple access points in a mesh configuration to optimise coverage in this band.

There may be instances (e.g. where coverage is required within buildings that are inaccessible, and where there is substantial attenuation of external radio signals) where the use of a lower frequency would be beneficial. This could be achieved by using the 1452 - 1479 MHz band, or alternatively by deploying a vehicular repeater on the wide area LTE network, or alternatively by deploying 802.11 technology in a lower frequency band (e.g. the “white spaces” in the UHF TV band), but the last of these approaches could have significant cost implications for terminals.

Although the 5150 - 5250 MHz band is shared with commercial WLAN systems, these are restricted to lower transmit powers and to use in indoor locations only, hence the likelihood of interference to PPDR users is very small; however, there is always the risk of a “near/far” problem, where a low power interfering station is much closer than the higher power PPDR station. We recognise that even a small risk of interference may not be acceptable.

The use of the 4940 - 4970 MHz could be considered as an alternative to the 5150 - 5250 MHz band; unfortunately, this band is currently used by the military and for radio astronomy applications in Germany.

Note that coverage limitations in the 5150 - 5250 MHz frequency range mean that multiple access points would be required to ensure reliable coverage at major incidents. Access to a lower frequency band such as 1452 - 1479 MHz would be attractive for optimising coverage at major incidents.

3.8.3 Spectrum to support air to ground links

We estimate that a **minimum of 15 MHz** (unpaired) is required on a harmonised European basis in the range 1 - 5 GHz to support air to ground video links, with potentially a **further 7.5 MHz** required to meet specific German requirements, based on our understanding of the requirements from the IABG report.

3.8.4 Spectrum for Backhaul

We believe that backhaul requirements for the wide area network can be met from existing microwave fixed link bands. It should not be necessary to reserve specific spectrum for public safety applications. Higher frequency fixed link bands such as 33 GHz or 58 GHz can also be used to support fixed installations such as CCTV surveillance, in preference to using scarce mobile spectrum.

4 PPDR spectrum needs in other countries

For a topic of such enormous importance, it is perhaps surprising that relatively few studies have been undertaken to date to quantify needs. No European study is as detailed or comprehensive as that which IABG conducted on behalf of the German Ministry of the Interior (see Section 3.1).

Gartner conducted a survey of PPDR communication requirements in 2008 on behalf of the Norwegian government (see Section 4.1). The survey includes an assessment of PPDR communication needs in Denmark, Sweden, and Germany as well. The focus is on application requirements, rather than being on spectrum needs.

Analysys Mason conducted a study of the likely evolution of European PPDR spectrum needs on behalf of the TETRA association (see Section 4.2). The study contains four possible scenarios for the future evolution of PPDR communications.

The United States has been concerned for many years about the need for spectrum for wireless broadband PPDR use, interoperable across the U.S. Despite deep concerns, especially immediately following the attacks of 11 September 2001, and despite unsuccessful efforts to auction a band for commercial use with PPDR pre-emption, relatively little has been concretely put in place to date. Section 4.3 discusses the assessment that the U.S. FCC conducted at national level; Section 4.4 discusses an assessment conducted by New York City, where these issues have a special resonance.

4.1 The Gartner study of Norway, Denmark, Sweden and Germany

A 2008 study by Gartner on behalf of the Norwegian government evaluated the TETRA technology as part of Norway's planning for its initial rollout of a national radio infrastructure for public safety called *Nødnett* in and around Oslo.⁴³ The study compared the functional requirements for *Nødnett* with requirements for other Command and Control Wireless Network Infrastructure for public safety in Denmark, Sweden and Germany. We have reproduced this comparison of requirements in Table 4-1. The study concludes that TETRA is the best technology for *Nødnett*, and that reliance on commercial wireless networks employing GSM/3G/CDMA EV-DO at that time would not have been appropriate or feasible.

⁴³ Gartner, Inc. (12. December 2008): A Report for Direktoratet for Nødkommunikasjon, *Nødnett - Market Analysis Technology*.

Table 4-1: Comparison of Public Safety Network Functional Requirements

Requirement	Description	Required in decision to procure		
	Norway	Sweden	Denmark	Germany
Same radio system in all of public safety	Common national radio system	Yes - Common national radio system used for public all public safety	Yes (incl. Police, Ambulance, Fire)	Yes
Encryption capabilities	Digital radio network (possibility to communicate without eavesdropping – Police, encrypt sensitive health data and encrypt firemen's communication). End to end encryption required.	Yes – no additional end-to-end encryption required	Yes – no end-to-end encryption required	Yes
VPN capability	Virtual Private Networks for organisations using it.	No – although system should support flexible cooperation and co-existence.	Yes	Yes
Nationwide coverage	Nationwide coverage	Yes	Yes	Yes
Voice quality	Good voice quality in noisy areas	Yes - Good voice quality in noisy areas	Yes	Yes
Support Group calls	Group calls, individual calls and data transmissions. Group calls across VPN's and geography	Yes - Support dynamic groups.	Yes	Yes – groups
Support individual calls	Yes	No	Yes	Yes
Support data transmissions	The system can transmit data as text messages, pictures, map sectors, ECGs and database lookups.	Yes	Yes	Yes
Paging	Include a pager solution	No	No	No ⁴⁴
Traffic prioritizations and alarm calls	Alarm calls and prioritized traffic	Yes	Yes	Yes
DMO support	Possibility of DMO. Direct Mode Operations enabling direct communication between units within range (when no base station is available)	Yes	Yes	Yes
Integration with other public safety networks	Integration/compatibility with public safety networks in adjacent countries to support cross border operations	Yes	Yes	Yes
High Availability	The infrastructure should be available in extreme circumstances including power outages and incidents were e.g. public telecom nets does not work.	Yes	Yes	Yes
Integration with PSTNs	The ability to call from/to phones in the public fixed and mobile networks	Yes	Yes	Yes

Source: Gartner, Inc.

⁴⁴ As noted later in this section of the report, we think that this is incorrect.

Most functions and characteristics are common to all four networks. These functions and characteristics include: encryption; voice quality; group calls; traffic prioritization and alarm calls; DMO support; integration with other public safety networks; and integration with the PSTN.

Of the four networks that they analysed, only the Norwegian network was listed as requiring a paging capacity; however, inasmuch as the German network does in fact provide paging (which is quite essential in light of the large number of volunteer firemen in Germany), we have our doubts about this part of their analysis.

They identified requirements for all four networks to support data transmission, but the Gartner report is short on details regarding the exact nature and capacity needs of these data streams. Data capabilities identified include image and video transmission; medical information; database access; and case management systems. Connectivity needed between ambulances and hospitals, and among police cars, mobile hand terminals and police stations.

With the exception of paging (which we believe to be in error), the functional requirements for the German Digitalfunk BOS network are the same as those for Nødnett.

4.2 The Analysys Mason study

Analysys Mason conducted a study on behalf of the TETRA Association on the future broadband needs for public safety networks.⁴⁵ The Analysys report contains a list of possible data applications required in future public safety networks including: mobile office; image transfer; biometric data; automatic number plate recognition; digital mapping and location services; remote database access; personnel monitoring; sensor devices/networks; remotely controlled devices; non-real-time video; and real-time video.

The study analyses four scenarios for the possible evolution of data usage: (1) steady growth; (2) data enhances voice; (3) information driven; and (4) full multimedia. These appear in Table 4-2.

Under *steady growth*, there are no major changes or spikes in observed trends, and data usage grows at a slow pace. TETRA and TEDS networks, complemented by commercial networks for non-mission critical data needs, carry all necessary data. Analysys does not believe that this strategy can be sustained in the long run.

⁴⁵ Analysys Mason (8 March 2010): Report for the TETRA Association: Public safety mobile broadband and spectrum needs, Final report.

In the *data enhances voice* scenario, public safety officials share data and multimedia applications on a many-to-many basis for situational awareness. Here, data applications become increasingly essential to mission-critical responsiveness.

Under the *information driven* scenario, data communications enhance mobile command and control. The enhancement of traditional command centres with mobile command centres facilitates response to major planned events, and can help to establish a common operating picture between the field and the command centre.

The *evolution* scenario would generate bandwidth demands that exceed the capabilities of current public and commercial networks, and would therefore require a new generation of dedicated networks. New ways of working evolve. With full reliance on multimedia, the intensity and range of data use would increase. Data applications would include telemedicine, 3D video forensics, and video of sufficient quality for evidential facial recognition. The data network would have to be capable of reaching a wide geographic area.

Table 4-2: Four alternative paths for use of data and multimedia applications within the safety sector

Usage	High	<p style="text-align: center;">Data enhances voice</p> <p>Incident response increasingly relies on situational awareness provided through data application on the move and access to a wider range of faster data applications used in a similar net-centric fashion to voice (e.g. group exchange of data)</p>	<p style="text-align: center;">Full multimedia reliance</p> <p>A diverse range of imaging and real-time video applications take off, with widespread use across the public safety sector to make real-time decisions at incidents</p>
	Low	<p style="text-align: center;">Steady growth</p> <p>Working methods change slowly, but voice is the dominant method of mission-critical communication. Existing data applications continue to be used along side of voice</p>	<p style="text-align: center;">Information driven</p> <p>Command and control becomes increasingly field based, and there is a requirement for access to office applications on the move as well as sharing of a range of information types (text, voice, images, video)</p>
		Low	High
Broadband data reliance			

Source: Analysys Mason

4.3 The U.S. FCC's support for the *National Broadband Plan*

An assessment of the spectrum needs for a national public safety broadband mobile network was presented in a recent FCC white paper as part of the U.S. government's National Broadband Plan (NBP)⁴⁶, which makes significant recommendations for improving access to broadband communications across the US. The assessment included a technical analysis of the capacity and performance needs going forward for national public safety broadband, based in part on actual experiences of a number of emergency situations. The main conclusions of the assessment were:

- The existing 2x5 MHz of dedicated broadband public safety spectrum in the US provides sufficient capacity for day to day communications and for some serious emergency scenarios.
- For the worst emergencies, even a further 2x5 MHz would be insufficient. Accordingly, priority access and roaming on the commercial networks is critical to providing adequate capacity in these extreme situations.
- The capacity and efficiency of a public safety broadband network would far exceed the expectations of users who have only experienced narrowband land mobile radio (LMR). This is because of the system architecture, density of cell sites, density of cell sectors per site, network and spectrum management, and the use of new and emerging technologies.
- To meet day to day fixed needs for applications like video monitoring, the public safety community should rely on other transmission technologies, such as fixed wireline and fixed wireless technologies, which will enable public safety to preserve its 700 MHz capacity for mobile broadband communications.

The white paper adopts a conservative view of likely bit rates for video transmission. It reports that the National Public Safety Telecommunications Council (NPSTC), which represents public safety bodies, has stated that support for 256 kbps per video device throughout the coverage area would be sufficient in urban areas, with lower rates acceptable in suburban and rural areas.

According to the Department of Homeland Security's SAFECOM Programme, the preferred data rate for video depends on its use. 256 kbps is acceptable for tactical and live surveillance of large targets; however, for small targets 512 kbps may be needed.

The paper notes that much higher data rates could be provided by using higher gain antennas and perhaps higher power transmitters, both of which are considered to be

⁴⁶ "The Public Safety Nationwide Interoperable Broadband Network: A New Model for Capacity, Performance and Cost", FCC White Paper, June 2010, <http://fcc.gov/pshs/docs/releases/DOC-298799A1.pdf>.

more feasible for public safety users than for public networks. A device with a high gain antenna at the edge of the cell can communicate as if it were much closer to the centre of the cell, reducing the effective consumption of network capacity.

Some of the assumptions used in the analysis are open to question. For example, there is a general assumption that in any incident the wireless traffic will be spread uniformly over the coverage area of several cells, so that the assumed capacity available is the sum of the capacity of these cells. In practice, it is more likely that there will be “hot spots” with very high traffic levels that are within the coverage area of only a single cell – particularly in rural areas, where the cell sizes are relatively large.

In our view, the FCC report underestimates the spectrum requirement for wide area communication, by assuming unrealistically low data rates for video transmission and by taking an optimistic view that coverage and capacity will be available from more than one cell site.

4.4 New York City government

As part of a submission to the U.S. Congress arguing for an additional 2 x 5 MHz to be made available for public safety use in the 700 MHz band, the police, fire and Information Technology and Telecommunications (ITT) departments of New York City jointly undertook an analysis of spectrum requirements based both (1) on estimated day to day requirements and (2) on a hypothetical major incident scenario.⁴⁷

The New York City analysis assumes higher bit rates for video applications than the FCC white paper (up to 1150 kbps is quoted, but 647 kbps is used in the uplink capacity analysis); however, these are still substantially lower than the 4 Mbps suggested in the IABG report. We consider the New York City values to be plausible. Like the FCC, however, the analysis assumes that traffic at an incident will be distributed across several cells.

The major incident scenario used in the analysis is a “dirty bomb” explosion at the City’s main rail terminal. 900 people are assumed to be injured, some of whom are in critical condition, there are a number of fires, and there is radiation contamination. The analysis assumes heavy use of video links, with 38 in the downlink direction and 12 in the uplink. There is an additional 16 Mbps of non-video traffic in the downlink and 7 Mbps in the uplink. The traffic is assumed to be uniformly distributed across six cell sectors.

⁴⁷ “700 MHz Broadband Public Safety Applications and Spectrum Requirements”, February 2010, Appendix A (www.psafirst.org/uploads/documents/NYC_Spectrum_Requirements-1.pdf).

4.5 Responses to our ECC/CEPT query

The German Ministry of Economics and Technology has invited members of CEPT/ECC to respond with any information that they might have in regard to spectrum needs for broadband PPDR. We received a limited number of responses.

The French ANFR responded⁴⁸ as follows:

The French administration supports the CEPT's initiative to identify harmonised spectrum for PPDR as one of a major challenge of ECC within the next five years (see ECC strategic plan) and will contribute to this activity within CEPT ECC FM 38.

The amount of envisaged PPDR spectrum in our country is still under investigation at this stage but it is assumed to be less than the requests provided in the ETSI SRdoc submitted to CEPT.

On the basis of the current ECC Decision (08) 05, the most suitable candidate bands should be within the bands 400 - 470 MHz (excluding the NATO bands), with an emphasis on the study to the 410 - 430 MHz band that shows potential for harmonisation (see French contribution to WGFM FM(09)102 based on the results of PPDR questionnaire). Moreover, it is also appropriate to implement broadband networks in the future spectrum to be allocated within the 400 - 470 MHz bands and not to break up spectrum into wideband and broadband (pushing broadband into higher frequency spectrum with prospects limited to long term).

The Austrian Ministry for Transport, Innovation and Technology, which is the spectrum management authority for Austria, responded as follows:

Broadband requirement:

- *As one of the key requirements, additional 60 MHz for broadband ad hoc networks is needed. It would be very helpful to define what amount of spectrum is needed in total and how much of this total amount is currently covered by existing regulations to avoid misunderstandings. According to the ECC Recommendation ECC/ERC/(08)04, 50 MHz in the band 5150 - 5250 MHz has been foreseen for BBDR purposes. So the question is, is the total amount of spectrum for ad hoc networks 110 MHz or 160 MHz?*

⁴⁸ The study team wishes to express our deep appreciation to the French ANFR, both for this contribution and for the information that they provided on spectrum re-farming in France since 1992 (see Section 5.6.2.3).

Indoor requirements:

- *Based on the information of the Austrian Ministry of Interior, additional spectrum for narrowband applications (extension of the current 2x5 MHz in the 380 MHz frequency band) will be needed in future. Currently they are focused on setting up a countrywide network in the existing band 380-385/390-395 MHz. There is no discussion on additional spectrum at this moment concerning this purpose.*
- *The term "if possible 14 MHz" of the indoor requirement should be clarified (may be "2x7 MHz" is meant).*
- *From the Austrian spectrum management point of view, it is difficult to find a contiguous block of 2x7 MHz in the band below 1 GHz.*

For Example, 2x7 MHz is not possible in the following bands in Austria:

- *the whole 2m-band*
- *410-430 MHz*

From our point of view, the 2nd half of the 380 MHz (385 - 390/395 - 399.9 MHz) band could be a candidate.

We have also had cordial interactions with Hans Borgonjen, who is active in the PPDR communications community in many roles; with the Ministry of Information Technology and Communications of the Republic of Moldova; and with a researcher at NATO.

5 Impact assessment of options for Germany

This section of the study provides an *Impact Assessment (IA)* of various policy options. Impact Assessment is a tool used extensively by the European Union to assess likely costs and benefits of proposed policy changes.

The analysis generally follows the procedures outlined in the European Commission's updated *Impact Assessment Guidelines* of 15 January 2009 (SEC(2009) 92). We have made minor adaptations where appropriate to simplify its structure, and to reflect the fact that we are applying the tool on behalf of Germany rather than the European Commission, and at the level of one Member State rather than for Europe as a whole.

Section 5.1 explains why we chose to use Impact Assessment as a means of characterising costs and benefits of a new harmonised spectrum allocation for broadband PPDR. Sections 5.2 through 5.8 provide the required structure of the Impact Assessment itself:

- Problem definition
- Policy context
- Objectives
- Policy options
- Analysis of impacts
- Comparing the options
- Monitoring and evaluation

5.1 Why an impact assessment?

This study was prompted by a perception on the part of many of those responsible for PPDR in Germany that existing spectrum allocations for PPDR are unlikely to be sufficient for future needs, and that action at European level may be superior to separate uncoordinated actions on the part of individual European countries.

We as the study team cannot take that as a “given”. It is clear in general that policy intervention is warranted only in cases where the anticipated benefits are likely to outweigh the anticipated costs, including administrative overhead costs. It would be inappropriate for us to recommend any action at European or national level without first taking a hard-headed look at who is impacted, positively or negatively, and how.

This might have been less of a concern had we been talking about a commercial spectrum assignment, where market mechanisms such as auctions and secondary markets help to ensure that spectrum is assigned to the highest valued use. In this

case, however, it is fairly clear that an allocation at European level to PPDR could never go through such a market test, for two main reasons. First, the practical hurdles to establishing (for example) a spectrum auction mechanism at European level, rather than at the level of the Member States, are overwhelming; and second, given the highly fragmented nature of the PPDR community, the economic transaction costs of aggregating the PPDR demands would appear to be insuperable. Thus, it would appear that it would be impractical to conduct a market test at European level, and even if it were practical it would be unlikely to generate a rational, appropriate result.

Given that a rigorous cost-justification was needed in any case, we have chosen to follow the same general procedure that the European Commission would be required to follow if it were to advocate a harmonised allocation. First, we observe that a harmonised allocation is unlikely to come into effect without active support from the Commission; and second, we note that Impact Assessment is the tool that the Commission itself would be required to employ in support of any harmonised allocation, were it to decide to do so. By formulating our analysis as the Commission would be required to formulate theirs, we hope to simplify and accelerate a decision at European level.

The Commission's *Impact Assessment Guidelines* of 15 January 2009 (SEC(2009) 92) describe a general methodology, but also reflect numerous mechanisms that are specific to the Commission's internal bureaucracy. In this study, we have followed the principles of Impact Assessment methodology, but we have made minor adaptations where appropriate to fit the circumstances of this study.

5.2 Problem definition

The general problem statement for spectrum for PPDR in Germany appears in Sections 2 and 3. We will not reproduce that discussion here.

Key elements of the problem in the German context are:

- Spectrum allocations harmonised at European level appear adequate for today's voice and narrowband data requirements; however, those spectrum allocations fall substantially short of anticipated future German requirements in the medium to long term for video and for high speed data (see Section 3).
- A Germany-specific solution might sacrifice important potential benefits of harmonisation. In particular, a Germany-specific solution is likely to entail (1) higher unit costs for PPDR communications equipment, (2) a lack of interoperability with PPDR units in adjacent European countries in the event of an incident near the border, and (3) significant barriers to loaning PPDR units to other European countries, or to benefitting from having PPDR units loaned to Germany, in the event of a catastrophe.

5.3 Policy context

Most European countries have built or are building TETRA or Tetrapol networks based on the harmonisation of spectrum for public safety that was put in place in the 380 - 400 MHz bands by the ECC in 1996. ECC Decision (ECC/DEC/(08)05) proposes that additional spectrum be made available in the 380 - 470 MHz band for wideband (rather than broadband) digital PPDR. An Annex to the Decision identifies the types of mobile system technologies that could be deployed. There are, however, significant barriers to the implementation of this decision, as explained in Section 2.1.

Most European stakeholders acknowledge the need for additional spectrum for PPDR data and video. ECC (primarily through PT 38) and ETSI are studying possible spectrum allocations and related technology in conjunction with PPDR.

To date, little solid work has been done in Europe to quantify emerging PPDR needs for high speed data and for video. Largely as a result, the various on-going initiatives have failed to produce much in the way of concrete results.

5.4 Objectives

An ideal solution, from the perspective of Germany, would in our view have the following characteristics:

- Sufficient spectrum would be available to enable efficient deployment and use of anticipated future PPDR communications equipment, including high speed data and video capabilities (including indoors when required).
- These communications solutions should be affordable. Notably, the price-performance of the associated equipment should reflect reasonable production economies of scale and scope. Costs of achieving coverage must be reasonable.
- PPDR communications equipment and applications used for predictable peaks, and for unpredictable catastrophes, should be substantially the same as those used every day.
- PPDR units operating near the border should be fully able to communicate and interoperate with PPDR units from neighbouring countries in the event of an incident that affects not only Germany, but also one of its neighbours.
- Germany's PPDR equipment should be fully interoperable with that of other European countries, so as to make it practical for Germany to lend forces to other European countries, and for other countries to lend PPDR forces to

Germany, in the event of a significant catastrophe, or of an event that requires specialised capabilities.

- Technical specifications of the associated equipment and communications protocols and applications should be such as to support the requisite production economies of scale, and a high level of technical interoperability.

If we were looking at this from an overall European perspective, rather than a German perspective, we might add:

- Recognising that some European countries are likely to have greater needs than others, any harmonised allocation of spectrum for broadband PPDR should strive to avoid obliging countries with lesser needs to allocate more spectrum than is required by their national circumstances.

5.5 Policy options

In the nature of the impact assessment process, it is necessary to abstract the options chosen so as to arrive at a number that is manageable for analysis. Typically, this means that between three and five options are evaluated.

The policy options that we have chosen for this IA are summarised briefly below, then discussed at greater detail:

- **Option 1: No change:** An impact assessment must always weigh potential interventions against the option of leaving things as they are. This option assumes that no additional spectrum is made available for PPDR applications.
- **Option 2: Let a thousand flowers bloom:** This option assumes *that individual European countries* allocate sufficient spectrum to meet their individual needs, but that no further harmonisation is undertaken at European or global level. It thus represents an alternative baseline case, assuming a greater degree of activism on the part of European countries.
- **Option 3: Harmonised solution below 1 GHz:** Additional and sufficient spectrum below 1 GHz is made available on an exclusive basis, harmonised at European level, for PPDR applications.
- **Option 4: Harmonised solution below 1 GHz and above 1 GHz:** Additional spectrum is made available on an exclusive basis, harmonised at European level, for PPDR applications. Spectrum above 1 GHz is used where feasible to augment capacity, so as to reduce the need for valuable sub-1 GHz spectrum.

Table 5-1: Options for the impact assessment

Options for the impact assessment
Option 1: No change
<ul style="list-style-type: none"> No additional spectrum allocations for PPDR at European level No additional spectrum allocations for PPDR at national level Continued use of spectrum in 380-400 MHz range for TETRA/TETRAPOL
Option 2: “Let a thousand flowers bloom”
<ul style="list-style-type: none"> No additional spectrum allocations for PPDR at European level European countries allocate sufficient additional spectrum for PPDR according to their individual needs Continued use of spectrum in 380-400 MHz range for TETRA/TETRAPOL
Option 3: Harmonised solution in bands or tuning ranges below 1 GHz
<ul style="list-style-type: none"> National augmentation of harmonised bands permitted within predefined tuning ranges Continued use of spectrum in the 380-400 MHz range (not necessarily contiguous with the new bands) for TETRA/TETRAPOL
Option 4: Harmonised solution in one or more bands or tuning ranges below 1 GHz, plus one or more bands or tuning ranges above 1 GHz
<ul style="list-style-type: none"> Lower bands or tuning ranges to meet requirements for coverage and building penetration Upper bands or tuning ranges to satisfy requirements for capacity / surges National augmentation of harmonised bands permitted within predefined tuning ranges Continued use of spectrum in the 380-400 MHz range (not necessarily contiguous with the new bands) for TETRA/TETRAPOL

Under all of these Options, commercial networks are used wherever feasible (consistent with application requirements for capacity, reliability, and robustness). Analogously, sharing of bands is assumed wherever feasible under all Options.

Our choice of options is closely linked to the comparisons that we are seeking to make. It is useful to distinguish between Option 1, Option 2 and Option 3 in order to show the opportunity costs of failing to deploy modern PPDR applications, independent of the incremental benefits of harmonisation at European level. The distinction between Option 3 and Option 4 then primarily serves to demonstrate differences between a straightforward “brute force” harmonised solution versus a more nuanced approach.

5.6 Analysis of impacts

This section assesses the impacts, positive and negative, of Options 1 through 4 on stakeholders. Section 5.6.1 identifies the major impacts, and identifies the parties impacted positively or negatively. Section 5.6.2 assesses the major impacts, qualitatively and (where feasible) quantitatively.

5.6.1 Identification of economic and social impacts

The most important impacts of Options 2 through 4 in comparison with the Option 1 (the “no change” option) are:

- An improvement in the overall effectiveness of PPDR response, with probable reductions in lives and property lost, reduced risk to PPDR personnel, and concomitant improvements in social cohesion in the aftermath of any major catastrophes.
- An opportunity cost in the spectrum allocated to PPDR use is not used for some other constructive purpose.
- Re-farming costs associated with relocating whatever applications are currently using the newly allocated spectrum to other spectrum bands, assuming that their function is still required.
- Increased cost of PPDR network operation.

An impact assessment normally needs to consider administrative costs of a policy intervention. In this case, we feel that these costs are not much affected by the choice of option. PPDR services would exist under all options, and radio spectrum will need to be managed (both for PPDR and for non-PPDR applications) under all options.

The improvement in the overall effectiveness of PPDR response benefits everyone. To the extent that it means that better protection is delivered for no greater cost, this generates benefits to all, whether they are victims or not. It also benefits PPDR workers, whose personal safety may be enhanced.

It is simplest to think of these benefits *net of the costs of deploying and operating the networks and applications that produce them*. These deployment and operational costs can be significantly influenced by large differences in the frequencies chosen; thus, there would be a huge difference in the cost of achieving coverage depending on whether spectrum were allocated at 800 MHz versus, say, 5,150 MHz. At the same time, small differences in the band result in only small differences in cost; thus the difference in coverage costs at, say, 700 MHz versus 800 MHz is small enough to ignore for the high level analysis that we are performing here. This enables us to make the simplifying assumption that *the benefits of making new high speed applications available are largely independent of which user relinquishes spectrum to make it available to PPDR*.

The opportunity costs particularly impact those who otherwise would have used a service that under Options 2 through 4 would not be available, or would only be available at greater cost. These costs are a function of the highest-valued use to which the spectrum could have been put to use, rather than being a function of the current use of the particular spectrum band that is ultimately chosen.

Re-farming costs, by contrast, are entirely a function of the current use of the spectrum. Costs include the “hard” costs of new equipment that has to be purchased, and of the staff resources to deploy the equipment, usually without down time during deployment. Costs also include “soft” costs of staff re-training and administrative overhead. These costs should also be viewed net of benefits – in some scenarios, the relocated application may have been overdue for modernisation in any case, and might benefit from the deployment of improved technology.

5.6.2 Qualitative and quantitative analysis of significant impacts

This section provides a more detailed review of the costs and benefits associated with choosing one of the four Options identified in Section 5.5.

From Section 5.6.2.1 through Section 5.6.2.4, we deal with the comparison of Options 2, 3 and 4 to Option 1. Section 5.6.2.1 considers the benefits associated with being able to use new technology capable of delivering high speed data and video, net of the costs of deployment and operation. Section 5.6.2.2 reviews the opportunity costs associated with using this spectrum for PPDR, and not for some nominally higher-valued use. Section 5.6.2.3 discusses in general terms the re-farming costs associated with relocating an existing application. Section 5.6.2.4 considers the incremental cost of operating a broadband PPDR network. Section 5.6.2.5 focuses instead on the costs and benefits of harmonisation, and thus relates to the relative merits of Options 3 and 4 in comparison with Option 2 (where sufficient spectrum is allocated on a national basis rather than a harmonised basis).

5.6.2.1 Improved PPDR arrangements: lives saved and property protected

The main reason for enhancing PPDR is, of course, to enhance its effectiveness in saving lives and protecting property both from everyday threats and from catastrophes.

Estimating the value of property saved is far more straightforward than estimating the value of lives saved.

5.6.2.1.1 Mechanisms

The most important mechanism for benefits is the value of the new applications that could be deployed. Many of these were identified in the IABG study⁴⁹ conducted on behalf of the German Ministry of the Interior (BMI). Conspicuous examples include the use of helmet cameras, and vehicular and aerial drones for particularly dangerous deployments. Improved ability to call up dense graphical information such as building plans could have obvious value to fire-fighters.

⁴⁹ Fritsche, Wolfgang/Mayer, Karl (20 Mai 2010): Studie zum mittel und langfristigen Kapazitätsbedarf der BOS in der drahtlosen Kommunikation, iABG.

Enhanced interoperability for incidents close to the border could generate further benefits, but these benefits will be available only under options 3 and 4, and even then only if technical standardisation and application standardisation is sufficient to enable meaningful interoperability. Note that TETRA has not truly achieved this level of interoperability today.

The ability to lend PPDR units to other European countries, and for other European countries to lend them to Germany, provides still more benefits. These benefits depend once again on achieving full interoperability, which suggests once again that technical standardisation (which is beyond the scope of this study) should be strongly promoted if there were a decision to proceed with Options 3 or 4.

All of these benefit mechanisms plays a significantly different role depending on whether one considers normal day to day operations, peak planned needs as a sporting event or concert, or natural disasters. The next sections consider these three cases, building on the previous work of the iABG study for the German Ministry of the Interior (BMI).

5.6.2.1.2 Day to day operations

Day to day PPDR operations involve responding to routine events such as vehicular accidents, traffic stops, fires, emergency medical services, and the investigation or prevention of crimes. The estimates in this section are more fully elaborated in Section 3.4.4.4.

Vehicular accidents are a daily occurrence in Germany. There are some 336,000 accidents on German roads per year. 34,000 of these per year result in serious injuries, including approximately 5,360 fatalities per year. We estimate that German police might need to deal with roughly 70 accidents simultaneously during the busiest hour.

Crime is similarly a daily event in Germany. In 2008, there were 6.1 million recorded crimes in Germany, equating to 16,712 incidents a day. This corresponds to approximately 2,500 simultaneous police crime responses at the busiest time across Germany as a whole.

Extrapolating from UK experience, we estimate that there are approximately 2,300 simultaneous ambulance callouts during the busiest hour in Germany, and 285 simultaneous fire service attendances across the country during the busiest hour.

Given the substantial number of incidents, relatively small savings could generate substantial benefits. Consider, for example, a recent study⁵⁰ that found the costs shown in violent crimes in the United States (including costs to the victim, costs to the

⁵⁰ “Murder by the Numbers”, Matt DeLisi et al., Iowa State University, 2010.

perpetrator, costs to the criminal justice system, and the perhaps surprisingly high but quantifiable amounts that others are willing to pay (insurance, avoidance) to avoid the costs of becoming a victim. If better technology leads to more effective law enforcement, resulting in deterrence of some number of crimes that otherwise might have occurred, those savings are entirely relevant in assessing the costs and benefits of the a spectrum allocation for PPDR broadband.

Table 5-2: Cost estimates per offense (2008 US dollars)

Offense	Victim costs	Justice costs	Offender productivity	Subtotal	WTP	Total
Murder	4,712,769	307,355	143,432	5,163,556	12,089,100	17,252,656
Rape	138,310	8503	4610	151,423	297,109	448,532
Armed robbery	29,711	15,060	4098	48,869	286,864	335,733
Aggravated assault	37,907	13,831	6557	58,295	87,084	145,379
Burglary	2049	2356	1025	5430	35,858	41,288

Source: “Murder by the Numbers”, Matt DeLisi et al., Iowa State University, 2010

In light of these rather high costs per incident, a relatively small number of crimes deterred would represent a quite substantial total welfare gain to society as a whole.

Similar claims could be made about faster or more effective response to fires, emergency medical incidents, and so on.

5.6.2.1.3 Concerts and sporting events

The normal tendency would be to think of concerts and sporting events as more-or-less a special instance of normal PPDR operations, inasmuch as these events are generally known in advance and can be planned for.

The events of July 24 at the Love Parade in Duisburg might suggest otherwise. A huge crowd panicked in a confined space, resulting in 21 deaths and numerous injuries.⁵¹ Who was at fault has not been clearly established, and this study team has no desire to involve itself in that discussion. We note, however, that press reports suggest that communication failures and deficiencies on the side of PPDR forces may possibly have

⁵¹ See, for instance, Der Spiegel, “Analysis of the Love Parade Tragedy: The Facts Behind the Duisburg Disaster, 28 July 2010, at <http://www.spiegel.de/international/germany/0,1518,708876,00.html>.

contributed to the problems that were observed.⁵² If this were to prove to be the case, it would obviously suggest that there was ample room for technical improvements.

At the same time, we would note that deployment of improved technology in the form of TETRA is already in progress in Germany.

5.6.2.1.4 Disasters

There is always a temptation to ignore natural disasters, or even man-made disasters such as terrorist attacks, inasmuch as they cannot be predicted. This is, of course, an error. As a 2006 World Bank review of their disaster relief activities noted, “Most natural disasters are foreseeable to the extent that it is possible to predict generally where an event is likely to occur at some time in the near future (but not precisely when or its magnitude).”

The more appropriate response would focus on *risk assessment* and *preparedness*. At a basic level, the statistical expectation of loss associated with a specific hazard is simply the product of the probability of a specific disaster occurring multiplied by the damage that would be caused, on average, if it did. One should invest more in preparedness and mitigation where the hazard-specific risk is high. Thus, the threat of an earthquake in Istanbul warrants an intensive response; an equally likely earthquake in a desert, where no one lives, would not warrant much of a response.

Over the past hundred years, there has been a dramatic increase in the number of natural disasters reported (see Figure 5-1), and in the associated property damage. This might be a function of an increase in tropical sea temperatures of up to 2 degrees Fahrenheit over the past century, which may have contributed to an increase in weather-related disasters;⁵³ it may be a general consequence of global warming;⁵⁴ or it

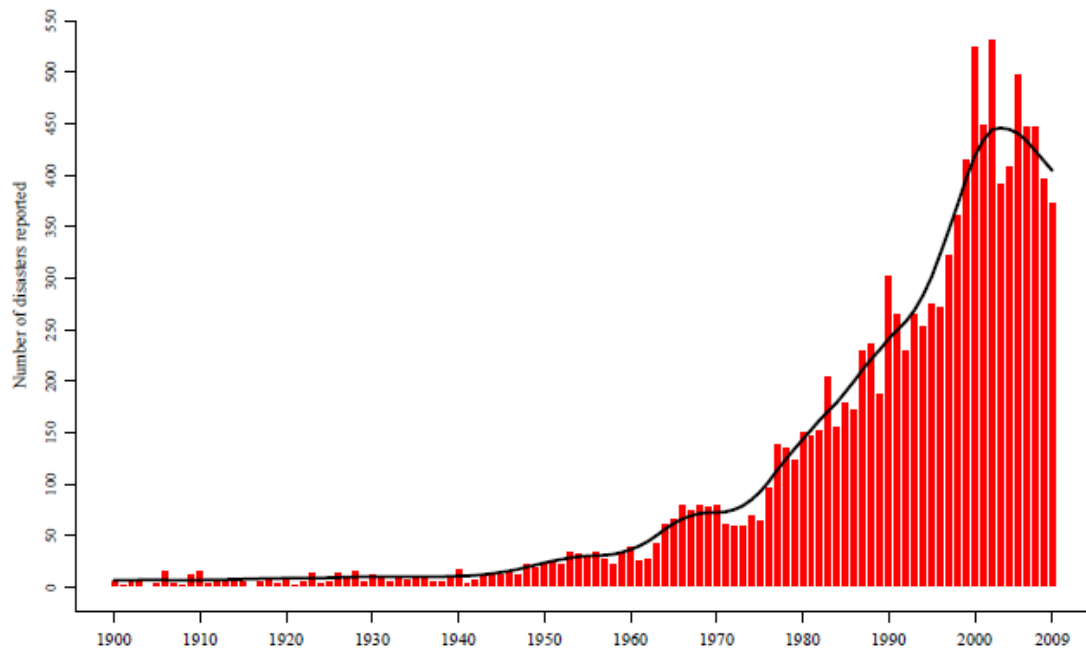
52 Der Spiegel, *ibid*. “Firemen and police officers on duty in Duisburg on Saturday said they had had problems with their analogue radios. Communication between officers had been difficult at best, and at times impossible. Was there a communications breakdown? Did the officers at the entrances to the tunnel not know that people were being crushed on the ramp? So far no one wants to comment on these questions. The radios ‘are in some cases so old that you can’t even get spare parts for them,’ said Andreas Nowak, a member of the police federation for the state of North Rhine-Westphalia, where Duisburg is located. Officers repeatedly get in dead spots where they are out of range and can’t be reached in emergencies. ‘Often officers take their private mobile because it’s the only way to stay in touch,’ said Nowak. But the mobile phone network collapsed on Saturday, so that wouldn’t have helped either.”

53 See the World Bank, Independent Evaluators’ Group (IEG), *Hazards of Nature, Risks to Development: An IEG Evaluation of World Bank Assistance for Natural Disasters*, 2006.

54 See The New York Times, “In Weather Chaos, a Case for Global Warming”, 14 August 2010. “Seemingly disconnected, these far-flung disasters are reviving the question of whether global warming is causing more weather extremes. The collective answer of the scientific community can be boiled down to a single word: probably. ‘The climate is changing,’ said Jay Lawrimore, chief of climate analysis at the National Climatic Data Center in Asheville, N.C. ‘Extreme events are occurring with greater frequency, and in many cases with greater intensity.’ He described excessive heat, in particular, as ‘consistent with our understanding of how the climate responds to increasing greenhouse gases.’ Theory suggests that a world warming up because of those gases will feature heavier rainstorms in summer, bigger snowstorms in winter, more intense droughts in at least some

might to a very significant degree simply mean that natural disasters that in the past would have been treated as purely local matters are today reported and recorded.⁵⁵

Figure 5-1: Natural disasters reported 1900 – 2009



Source: EM-DAT: The OFDA/CRED International Disaster Database⁵⁶

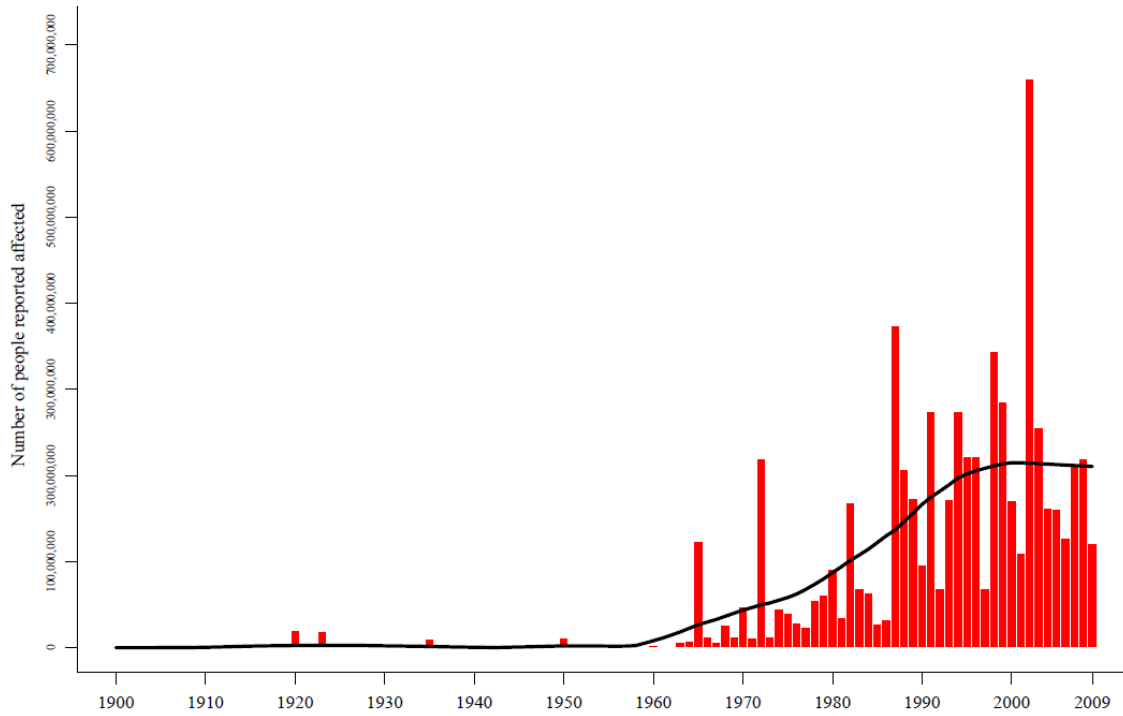
The number of deaths caused by these natural disasters has tended to decline over the past hundred years, but whether that will be the case for 2010 remains to be seen. Meanwhile, the number of people affected by natural disasters is reported to have increased enormously, as has property damage as a result of natural disasters, as shown by Figure 5-2 and Figure 5-3.

places and more record-breaking heat waves. Scientists and government reports say the statistical evidence shows that much of this is starting to happen. But the averages do not necessarily make it easier to link specific weather events, like a given flood or hurricane or heat wave, to climate change.”

⁵⁵ World Bank, op. cit.

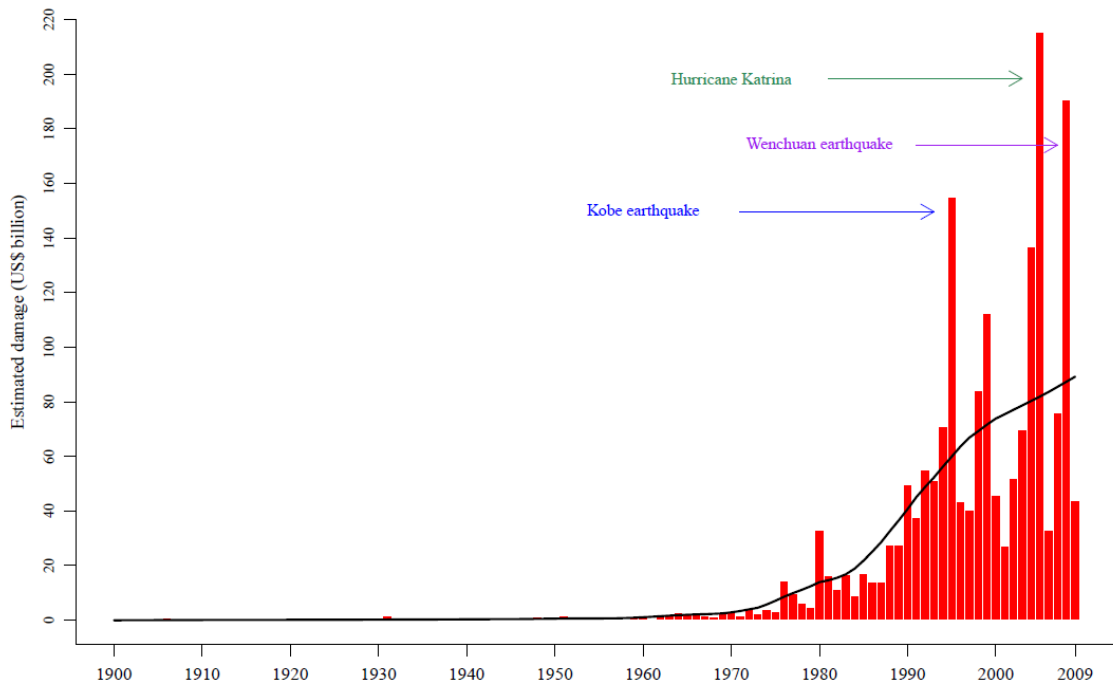
⁵⁶ Université Catholique de Louvain, EM-DAT, Brussels, Belgium, at www.emdat.be.

Figure 5-2: Number of people reported affected by natural disasters 1900 – 2009



Source: EM-DAT: The OFDA/CRED International Disaster Database

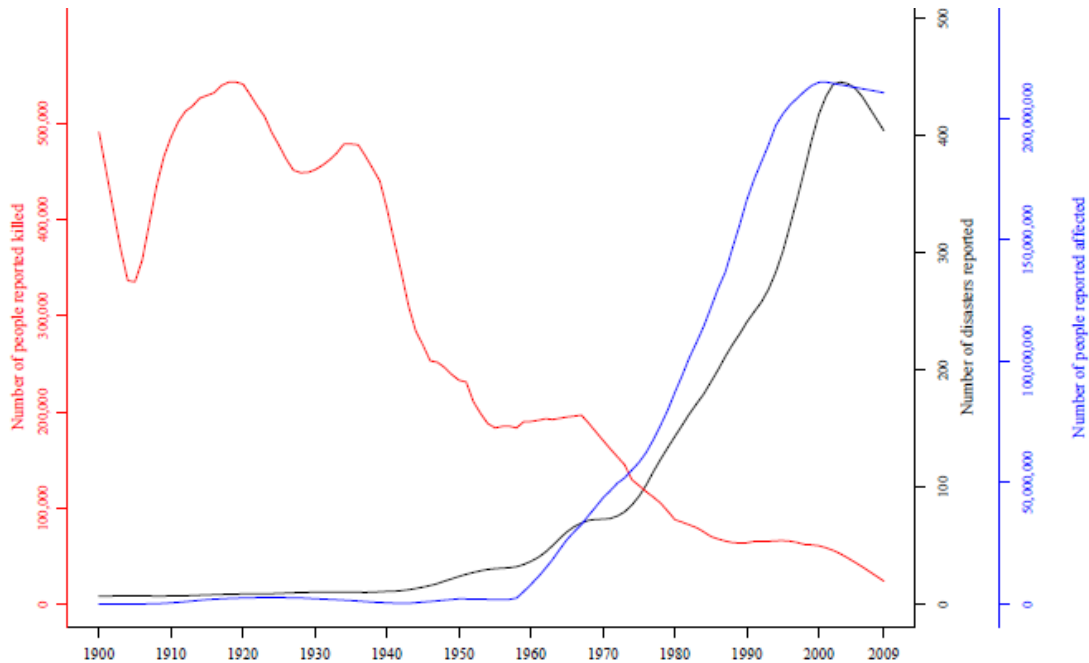
Figure 5-3: Estimated damage (US\$ billion) caused by reported natural disasters 1900 – 2009



Source: EM-DAT: The OFDA/CRED International Disaster Database

Figure 5-4 shows the decline in the number of reported deaths caused by significant natural disasters to be quite striking in the face of an increase in the number of disasters reported, in the number of people affected, and in the amount of property damage caused. A possible interpretation – although certainly not the only possible interpretation – is that improvements in prediction and mitigation (including medical advances) over the past hundred years have been effective as regards preventing loss of life, but apparently less so for protecting property.

Figure 5-4: Natural disaster summary 1900 – 2009 (linear-interpolated smoothed lines)



Source: EM-DAT: The OFDA/CRED International Disaster Database

We in Europe can be thankful that we are less subject to natural disasters than many other parts of the world, as can be seen in Table 5-3. Indeed, the World Bank estimates that some 95% of all damage due to natural disasters occurs in developing countries, partly because the presence of natural hazards is one of the reasons why they are developing rather than developed, and partly because their less developed infrastructure means that the impact of a natural disaster tends to be far greater both in relative and in absolute terms than might be expected in a developed country.

Table 5-3: Average annual damages (\$US billion) caused by reported natural disasters 1990 – 2009

Damages (2009 US\$ bn)	Africa	Americas	Asia	Europe	Oceania	Global
Climatological 2009	0.00	1.23	0.06	0.12	1.30	2.71
<i>Avg. 2000-08</i>	<i>0.05</i>	<i>2.36</i>	<i>3.47</i>	<i>3.15</i>	<i>0.36</i>	9.39
Geophysical 2009	0.00	0.30	3.10	2.50	0.16	6.06
<i>Avg. 2000-08</i>	<i>0.73</i>	<i>0.72</i>	<i>17.90</i>	<i>0.31</i>	<i>0.00</i>	19.67
Hydrological 2009	0.15	1.33	5.23	0.97	0.19	7.88
<i>Avg. 2000-08</i>	<i>0.37</i>	<i>2.99</i>	<i>9.05</i>	<i>7.01</i>	<i>0.52</i>	19.94
Meteorological 2009	0.02	10.37	7.53	6.65	0.07	24.64
<i>Avg. 2000-08</i>	<i>0.08</i>	<i>39.93</i>	<i>10.30</i>	<i>3.01</i>	<i>0.31</i>	53.63
Total 2009	0.17	13.23	15.91	10.24	1.73	41.28
<i>Avg. 2000-08</i>	<i>1.23</i>	<i>45.99</i>	<i>40.72</i>	<i>13.49</i>	<i>1.19</i>	102.63

Source: CRED, Annual Disaster Statistical Review 2009

Nonetheless, Europe is subject to significant hazards, and Germany is no exception. The European Commission's web site⁵⁷ lists quite a few natural disasters and major accidents in Germany, including Hurricane Lothar in 1999, the flooding of the river Elbe in 2002, and Hurricane Kyrill in 2007. Other examples demonstrate the diversity of threats to which Germany is exposed:

- 2007: Storm; 11 dead
- Aug-2003: Extreme temperature; 9,355 dead
- 7-Jun-2003: Storm; 10 dead
- 11-Aug-2002: Flood; 27 dead
- 26-Oct-2002: Storm; 11 dead
- 1999, Storm; 15 dead
- 1998: ICE train accident in Eschede; 101 dead
- 1997: Oder flood; damage EUR 327.4 million, 2,300 evacuated
- 1988: Aircraft crash at Ramstein air display; 70 dead, more than 400 injured
- 1987: Explosion of tanker holding 36,000 litres of gasoline at Herborn; 5 dead, 38 injured
- 1986: Fire at Sandoz in Basel; heavy pollution of the river Rhine (Germany/Switzerland)
- 1962: Tidal wave and flooding in Hamburg; 400 dead, more than 100,000 people affected, 50 dyke bursts

⁵⁷ See http://ec.europa.eu/echo/civil_protection/civil/vademecum/de/2-de-6.html.

As a notable recent example, a number of European countries, including Poland, Germany, Austria, the Czech Republic, Hungary, Slovakia, Serbia and the Ukraine experienced serious flooding in May, June and August of 2010. Dozens of people have died, tens of thousands have been evacuated, and billions of euros in damages have been incurred.⁵⁸

The flooding along the German – Polish border is particularly relevant for this report. The governments of Germany and Poland have both acknowledged the need for improved joint planning and joint response as a result. According to one press report, “Poland and Germany are to establish teams of experts to tighten cooperation in flood prevention following heavy rains this month which flooded the border region between the two countries. The two sides are drafting procedures for a better exchange of data concerning the hydrological and meteorological situation in the border region as well as coordination of rescue services. The teams of experts will also comprise fire service and police chiefs at local government and district level from both countries.”⁵⁹

The consequences of coordination, or lack of it, are clear. German authorities in “... the town of Goerlitz on the German side of the Nysa border river ... strongly complained about late notification they received concerning the developments on the Polish side.”

Given (1) the large numbers of people impacted by a natural disaster, (2) the considerable potential for property damage, and (3) the risk to social cohesion in the aftermath of a disaster, it is clear that even small improvements in the effectiveness of PPDR could have large benefits. Further, it is clear that there is ample room for improved ability to coordinate and interoperate.

The flooding also demonstrates the potential benefits of loaning PPDR forces from one European country to another. “Among the individual EU member states who have so far sent rescuers and equipment are France, Germany, the Baltic nations of Lithuania, Latvia and Estonia, and Poland's neighbour the Czech Republic, which has also been hit by floods.”⁶⁰ We are not in a position to estimate the economic magnitude of benefits, but one can reasonably infer that enhanced communications capabilities and enhanced communications interoperability could generate benefits at times and places where they are sorely needed.

Returning to Table 5-3, Europe experienced \$10.24 billion US in disaster damages in 2009, compared with an annual average from 2000 through 2008 of \$13.49 billion US. Germany represents about a sixth of European population, and about a fifth of European GDP, so one could expect about \$2 billion US of damage per year caused by disasters.

⁵⁸ See, for instance, Reuters, “Flash floods inundate central Europe”, 8 August 2010.

⁵⁹ thenews.pl, “Poland and Germany on joint flood prevention programme”, 17 August 2010.

⁶⁰ RTE, “Flood waters reach Warsaw”, 21 May 2010, at <http://www.rte.ie/news/2010/0521/poland.html>.

Improvements in the effectiveness of disaster response could thus have a quite substantial impact.

5.6.2.2 Opportunity costs associated with spectrum use for PPDR

The opportunity cost refers simply to the cost of not using a particular quantity of spectrum for some other beneficial purpose. How much value to society is sacrificed?

One way to assess opportunity cost is simply to note how much a knowledgeable buyer would have been willing to pay to use a similar block of spectrum for its most promising alternative use. Fortunately, Germany has just completed a spectrum auction that included many bands that are directly comparable to the bands that we would regard as most promising for PPDR. The winners were, in all cases, mobile network operators who intended to use the spectrum for mobile voice and data. Mobile network operators have consistently been willing to spend more than other bidders at spectrum auctions, which tends to confirm that mobile data and voice tends to be the highest valued use as conventionally measured.

Note that the opportunity cost depends on the highest valued potential use for the spectrum in question, not on the use it is being put to today. Whether the spectrum is currently used for mobile telephony, or free-to-air broadcasting, or by the military is irrelevant in terms of the opportunity cost.

In Germany's recent spectrum auctions, 800 MHz spectrum fetched an enormously higher price per MHz than did 1800 MHz or 2100 MHz. Specifically, the auction exhibited a willingness to pay as shown in Table 5-4.

Table 5-4: Opportunity costs for spectrum based on the recent German spectrum auctions

Band	Price per MHz for Germany
800 MHz	€59,607,917
1800 MHz	€2,087,100
2000 MHz	€8,790,025
2600 MHz paired	€1,841,457
2600 MHz unpaired	€1,730,360

The value of the 800 MHz spectrum is a reasonably good proxy, in our view, for the opportunity cost of allocating spectrum under 1 GHz to PPDR broadband use in Germany. With that in mind, we use €60 million per MHz as an estimate of the opportunity cost of allocating spectrum under 1 GHz to PPDR, and €2 million per MHz as an estimate of the opportunity cost of allocating spectrum over 1 GHz to PPDR.

5.6.2.3 Re-farming costs associated with spectrum use for PPDR

The *benefits* of using a re-farmed band (or bands) are presumably no different from those of using a band that were otherwise somehow vacant; however, in computing societal socio-economic welfare, the benefits must be considered net of the *costs* of relocating the existing application (assuming that the current user cannot share the spectrum with PPDR use) and of any other costs associated with re-farming the band. The primary cost arising from harmonisation is the opportunity cost of existing (and future) uses of spectrum being displaced by PPDR use. In order to assess those opportunity costs, it is necessary to identify and predict the alternative uses that exclusive allocation to PPDR would preclude.

5.6.2.3.1 Components of re-farming cost

Since all spectrum has already been allocated and assigned to some form of use, reallocating any particular frequency band to a new use or assigning it to a new user necessitates first clearing the band of the incumbent user(s). This re-farming process can involve relocating the incumbent user to a new frequency band, providing it with equivalent non-wireless network facilities or even require it to share the band with new users. The incumbent use might not be completely eliminated.

In this re-farming process, there are a range of tangible costs associated with relocating an existing application, some of which can readily be quantified. Much harder to quantify are “soft” costs such as disruption and re-training. Some typical re-farming costs are highlighted in Table 5-5.

Table 5-5: Costs and input variables associated with re-farming

<ul style="list-style-type: none"> • Original equipment / system costs • Equipment / system Replacement Costs • Relocation Costs (including transition costs of parallel equipment operation and (re)training) • Transition Time • Number of assignments • Number of transmitters • Number of receivers • Coverage, capacity, and in-building penetration costs • Interference mitigation costs
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Source: WIK

In relocating users from one band to another, equipment may need to be upgraded or replaced. For example, antennas might not be able to be reused if the new band is not in an adjacent or a harmonic multiple tuning range; however, towers and feeder cables

might be reused. The existing user might lose some capability if the new band is less suitable than the old, or *vice versa*. At the same time, any loss of capability might be offset if the new equipment is more advanced, and thus more efficient, than the old.

There are more complex costs associated with the disruption of the transition. New equipment has to be distributed to the users, and they might have to be persuaded to actually use it. Equipment operators probably have to be re-trained. There might also be operational costs or inconvenience associated with parallel operation of old equipment and new during the transition period.

If re-farming is required, a funding arrangement that compensates current incumbent users may be appropriate as a means of accelerating the clearing of the band. Compensation arrangements of this type have been common practice in France. Note, incidentally, that a previous study on behalf of the European Commission recommended wider use of compensation for band clearing costs.⁶¹ Of particular relevance for purposes of this study is that, where users were to be compensated, there will have necessarily been a study of the costs that had to be compensated. These analyses then become a good source of data on re-farming costs.

5.6.2.3.2 Estimating re-farming costs

Re-farming costs, unlike opportunity costs, are *entirely a function of the current use* of the spectrum. Costs include the “hard” costs of new equipment that has to be purchased, and of the staff resources to deploy the equipment, usually without down time during deployment. Costs also include “soft” costs of staff re-training and administrative overhead.

Re-farming costs should be considered net of any benefits of re-farming. In some scenarios, for instance, the relocated application may have been overdue for the deployment of improved technology in any case.

We do not have sufficiently detailed information to enable us to make detailed band-specific comparisons of re-farming costs; moreover, we think that it would be counter-productive for us at this early date to make a recommendation as to which spectrum should be re-farmed, and *from whom*, in order to create a broadband PPDR capability. We think that this is a complex negotiation that is best undertaken by the involved parties themselves. We are, however, convinced that win-win solutions are possible, and we encourage the parties concerned to seek them out.

⁶¹ See J. Scott Marcus, John Burns, Phillipa Marks, Frédéric Pujol, and senior expert Prof. Martin Cave, *Optimising the Public Sector's Use of the Radio Spectrum in the European Union*, available at: http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/studies/digital_dividend_2009/dd_finalreport_executivesummary.pdf, http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/studies/pus_2008/pus_study_2008_1_finalreport.pdf, and http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/_document_storage/studies/pus_2008/pus_study_2008_2_annex.pdf. Note that two of the authors are also authors of this study.

In order to obtain a rough estimate of re-farming costs, we look at spectrum costs as measured by megahertz per population of relocations completed in the United States and France. In Table 5-6, we present one spectrum relocation completed in the US and five relocations completed in France since 2001.

Beginning in 2001, the National Telecommunications and Infrastructure Administration (NTIA) began planning to relocate federal civilian and military users in the 1710 MHz to 1850 MHz band. The Commercial Spectrum Enhancement Act (CSEA), signed into law in 2004, directed the creation of a Spectrum Relocation Fund (SRF) through which federal agencies could recover the costs of relocation to other bands. The NTIA estimated re-farming costs in some detail, and the spectrum to be re-farmed was assigned to private sector users for AWS/UMTS systems by an auction held by the Federal Communications Commission (FCC). After several revisions of the estimate, the NTIA determined the aggregate cost of relocating the 12 federal agencies and the Department of Defense which use the band to be US \$1,008,552,502.⁶² Of this figure, US \$355,351,524 was related to Department of Defense re-farming. The SRF was funded by proceeds from the FCC's Auction 66, which dealt with Advanced Wireless Services (AWS-1) for the 1710 MHz to 1755 MHz band. The CSEA also stipulated a reserve price for total auction revenues of 110% of estimated relocation costs. Auction 66 was completed on 18 September 2006 and generated US \$13,879,110,200 in gross bids.⁶³ Relocation for military users in the 1755 MHz to 1850 MHz band is on-going.

France routinely compensates military and civilian government users who are obliged to vacate a band to enable a new civilian application. Since 1992, the Agence Nationale des Fréquences (ANFR) has re-farmed some 1400 MHz of spectrum through various processes. ANFR is required to estimate the costs and the budget for these relocations. It is responsible for managing the implementation schedule, and for controlling costs. As part of this process, ANFR manages the Spectrum Re-farming Fund (FRS). The FRS is funded from the national budget and from fees paid by the new spectrum users (when the new licensee can be identified). Re-farming is financed by the FRS on a case by case basis.

Comparing the US and the French experiences in re-farming spectrum yields a range of about €0.001 to €0.05 for cost per megahertz per POP (i.e. population), as can be seen in Table 5-6.

⁶² US Office of Management and Budget (16 February 2007): Commercial Spectrum Enhancement Act: Report to Congress on Agency Plans for Spectrum Relocating Funds, available at: http://www.ntia.doc.gov/reports/2007/OMBSpectrumRelocationCongressionalNotification_final.pdf.

The federal agencies were: Department of Agriculture; Department of Defense; Department of Energy; Department of Homeland Security; Department of Housing and Urban Development; Department of the Interior; Department of Justice; Department of Transportation; The US Treasury; National Aeronautical and Space Administration, Tennessee Valley Authority; and US Postal Service. Ibid.

⁶³ Federal Communications Commission (2006): Summary for Auction 66, available at: http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=66.

Table 5-6: Comparison of Band Re-farming Costs

Country	Year(s)	Band	Spectrum quantity in MHz	Transferred from	Relocation Cost in 000€	Population Affected in 000	Cost MHz/POP
US	2007-2010	1710 MHz	45	12 Fed Agencies & DoD	€737,288	301,290	€0.05438
FR	2001	1800 MHz	150	Defence	€7,000	59,476	€0.00078
FR	2001	2 GHz	140	Defence & FT	€38,000	59,476	€0.00456
FR	2001	2.4 GHz	83.5	Defence	€8,000	59,476	€0.00161
FR	2002-2010	DTT	320	Analogue broadcast	€57,000	61,181	€0.00291
FR	2001	PMR446	0.1	SNCF & RRs	€120	59,476	€0.02018

Sources: NTIA, ANFR and WIK estimates

For the six reference cases that we have available, we find that the cost of clearing a band was in the range of €0.001 to €0.05 per MHz/POP. Expressing the cost in terms of MHz/POP enables us to factor it up or down appropriately for larger or smaller bands, and for larger or smaller countries.

5.6.2.4 Network operation costs associated with spectrum use for PPDR

The deployment of new broadband PPDR services depends on the deployment of a new broadband PPDR network. In general, the benefits of the new services should be considered *net of the costs of operation of that network*.

In the near term and possibly in the medium term, those costs are likely to be significant, inasmuch as PPDR agencies will be obliged to operate a second PPDR communications network in parallel with the first. There are likely to be economies of scope – for example, sharing of towers, sharing of operational staff – but there will still be incremental costs.

In the longer term, these incremental costs are likely to disappear. Just as conventional fixed and mobile networks are evolving into IP-based Next Generation Networks, one can reasonably expect that these broadband PPDR networks will in the longer term absorb the functions of the current TETRA/Tetrapol networks. Indeed, there are already indications that TETRA will evolve to become a service over LTE, which might well become the technology of choice for future broadband PPDR networks.

Once that occurs, the cost of operation of a single integrated PPDR network that carries voice, data and video is likely to be no greater than that of the current TETRA network.

Indeed, it might well be less than that of the current network, inasmuch as the new network will be based on more advanced and more efficient technology.

Viewed in this way, incremental network operation costs can be considered to be a transitional issue rather than a long term concern.

5.6.2.5 Spectrum band harmonisation considerations

The discussion up to this point has been in terms of commercial services, shared use or exclusive use under the administration of a single country, which is to say a single *Spectrum Management Authority (SMA)*. In this section, we consider the benefits (Section 5.6.2.5.1) and the costs (Section 5.6.2.5.2) of a set of allocations or tuning ranges harmonised at European level.

As noted in ECC Report 80 on *Enhancing Harmonisation and Introducing Flexibility in the Spectrum Regulatory Framework*⁶⁴, market mechanisms can, in certain circumstances, be expected to result in industry-led *de facto* harmonisation where the benefits of harmonisation outweigh the costs.

“Harmonisation may be achieved in different ways. From a spectrum management point of view, harmonisation currently relates primarily to de jure spectrum harmonisation, i.e. to mandatory measures facilitating the coexistence of the different equipment or networks. De facto harmonisation may occur when, for instance, in response to market forces or perceptions of economic or commercial advantage, service providers and equipment manufacturers adopt similar usages in a given frequency band. It should be noted that the underlying technical assumptions made during the spectrum management decision-making process also affect flexibility and therefore need to be taken into consideration.”

In the case of broadband PPDR spectrum, however, given the small manufacturing volumes involved, we consider it unlikely that harmonisation would occur in the absence of concerted action at European level.

5.6.2.5.1 Benefits of harmonisation

There are a number of recognized benefits that tend to arise from the harmonisation of spectrum in general, all of which are relevant to PPDR. These benefits include:

- a broader manufacturing base and increased volume of equipment resulting in economies of scale and expanded equipment availability;

⁶⁴ See p. 4: <http://www.erodocdb.dk/Docs/doc98/Official/Pdf/ECCRep080.pdf>.

- enhanced cross-border coordination;
- increased potential for interoperability, with increased possibilities for circulation of equipment and staff; and possibly
- improved spectrum management and planning.

Section 5.6.2.5.1.1 discusses the benefits of production economies of scale, while Section 5.6.2.5.1.2 discusses the benefits that flow from enhanced interoperability.

5.6.2.5.1.1 Production economies of scale

Harmonisation of spectrum, together with full and effective technical standardisation, will enable *economies of scale* that can reasonably be expected to lead to lower unit costs for production of PPDR communications equipment. This same phenomenon is one of the key factors that has contributed to a steady decline in the unit price of mobile telephone handsets in the general marketplace; however, the manufacturing volume of mobile handsets is many times greater than that of PPDR communications equipment. The benefits of harmonisation and standardisation are likely to be considerably greater for PPDR communications equipment than for mobile handsets, however, because the volume of PPDR equipment manufactured would tend to be inefficiently small in the absence of harmonisation and standardisation.

Reduced unit cost for PPDR communications equipment would tend to be reflected in any of a number of ways, all of which are beneficial overall. It might mean that PPDR organisations can afford to equip more of their respective staff, or to provide more equipment or better equipment. All of these are likely to lead to productivity improvements for PPDR forces, and also to improved safety for PPDR forces. Given that PPDR forces are constantly in harm's way in order to protect the public, any improvement in their personal safety in carrying out their duties is important. Indeed, all of these benefits are likely to have substantial multiplier effects from the perspective of society at large, but their value is not easily reduced to purely economic terms.

Alternatively, lower unit costs could enable a reduction in the budget of PPDR organisations at a constant level of equipment deployment and quality.

5.6.2.5.1.2 Enhanced cross-border operation, improved interoperability

The PPDR sector tends to be fragmented. Many small organisations, often operating at the local level, provide a range of police, fire, health, and public safety services to the general public. This fragmentation complicates a coordinated response when a natural disaster or terrorist incident crosses national borders.

There is an increasing recognition of the need for solutions that are interoperable across national borders. Many European countries have at least partly migrated their emergency service communications to digital trunked mobile networks (either TETRA or

Tetrapol) operating in the harmonised 380 - 400 MHz band. TETRA and Tetrapol provide for voice and for narrowband data, but are considered to be inadequate for higher speed data transfer, and for video. Moreover, although TETRA and Tetrapol are nominally harmonised and standardised, in reality it is *by no means assured* that PPDR forces from one European country would be able to use their equipment successfully in another European country.

Natural disasters, terrorist incidents, and large scale accidents could well have international impacts. The lack of highly capable, fully interoperable solutions represents an unrealised opportunity to lower the risk to lives and property.

To give just one example, consider the crash of a commercial Boeing 737-222 jetliner, Air Florida Flight 90, on 13 January 1982. The plane crashed just after take-off onto the 14th Street Bridge, which is the link between Washington, DC and the state of Virginia. The crash thus took place squarely at the point of intersection of the authority of the US government and of two US states. Attempts to rescue survivors were likely hampered by the lack of interoperable communications between the US Coast Guard, the National Park Service, and PPDR workers from Virginia and Washington, DC. Seventy-eight people died in that crash. Five people were successfully rescued, but many who otherwise might have survived the crash perished in the icy water of the Potomac River.

The flooding that took place along the border between Poland and Germany provides a particularly timely reminder, not only of the need for cross-border cooperation, but also of the potential for mutual assistance. “Among the individual EU member states who have so far sent rescuers and equipment [to Poland] are France, Germany, the Baltic nations of Lithuania, Latvia and Estonia, and Poland's neighbour the Czech Republic, which has also been hit by floods.”⁶⁵ Clearly, this assistance will be far more effective if communication capabilities are fully interoperable.

Germany is reported to have bilateral agreements for mutual disaster assistance in place with numerous countries,⁶⁶ including:

- Belgium
- Denmark
- France (the 1977 Agreement between France and Germany)
- Lithuania
- Luxembourg (the 1978 Agreement between the Grand Duchy of Luxembourg and Germany)

⁶⁵ RTE, “Flood waters reach Warsaw”, 21 May 2010, at <http://www.rte.ie/news/2010/0521/poland.html>.

⁶⁶ See the European Commission's web site, at: http://ec.europa.eu/echo/civil_protection/civil/vademecum/de/2-de-1.html#lega.

- The Netherlands
- Austria
- Poland
- Russia (the 1992 Agreement between Russia and Germany)
- Switzerland
- The Czech Republic (the 2000 Agreement between the Czech Republic and Germany)
- Hungary (the 1997 Agreement between Hungary and Germany).

A number of us studied these issues for the European Commission's 2008 project "Optimising the Public Sector's Use of the Radio Spectrum in the European Union". In the course of the study, interviewees were emphatic about the need for more capable, interoperable solutions.

Interview respondents in that study placed particular emphasis on growing cross-border needs for routine matters dealt with every day. They also argued credibly that if interoperable solutions were not in routine use, they would be unlikely to prove satisfactory at the time of an international catastrophe.

5.6.2.5.2 Costs of harmonisation

The benefits of PPDR harmonisation and standardisation were noted in Section 5.6.2.5.1; however, while harmonisation can generate significant benefits, it also implies certain costs. It is therefore appropriate to balance the benefits against the costs incurred to meet the objectives.

The first and perhaps most obvious cost is some loss of ability to customise spectrum allocations to meet national circumstances. PPDR forces do not operate in exactly the same way in every country; consequently, there could be substantial national differences in how much spectrum is needed in support of broadband PPDR. Furthermore, existing spectrum allocations, assignments and usage could vary from one country to the next, meaning that an assignment that is workable in one country might be problematic (due for instance to harmful interference to PPDR communications, or to harmful interference caused by PPDR communications) in another. A harmonised allocation necessarily reduces the ability to customise the allocation to accommodate variation in national circumstances.

This defect might be mitigated to some degree by defining harmonised *tuning ranges* rather than firm, specific harmonised allocations. A defined tuning range might require each country to allocate at least some minimum amount of spectrum, and within a tight enough frequency range to enable efficient equipment design, but would still enable

some national flexibility as to the exact size and placement of the band. A tuning range solution would make sense only if broadband PPDR equipment were capable of dynamically and automatically identifying the available bands in the operating environment in which the equipment finds itself.⁶⁷

Whether PPDR spectrum were allocated at national level, versus harmonised at some European level, it is unlikely that it would be allocated using market mechanisms such as auctions. PPDR in general can be viewed as an excellent example of an economic *public good*. Its value to society greatly exceeds its private value. Moreover, the fragmented PPDR provider community would likely encounter substantial economic transaction costs in attempting to aggregate their demand in order to coordinate a bid for PPDR spectrum. For both of these reasons, an auction could not properly reflect the value of PPDR spectrum to society, either in a national or a European allocation scenario. Consequently, some form of administrative allocation of spectrum rather than an auction would be appropriate in the case of broadband PPDR.

The possible risks of any administrative allocation are that spectrum is “sterilised” before the successful deployment and use of the designated application is proven. If the designated application somehow fails, this imposes *opportunity costs*, where the benefits from potential alternative applications are foregone. As a result, alternative services or technologies would be denied access to spectrum, potentially leading to delays in innovation, reduced inter-application competition, and loss of consumer benefits.

These costs are potentially present whether spectrum for broadband PPDR is allocated at national level or at a harmonised European level; however, the risks and costs may be greater in the harmonised case. First, there could be delays and inefficiencies in achieving agreement and implementation of harmonisation measures. Second, once harmonisation is achieved, it will tend to have a momentum of its own, implying significant increased transaction costs and delay in reclaiming the spectrum if broadband PPDR applications were for some reason to fail to deploy successfully in the band or bands. We do not consider this to be a great risk in this case, but it is clearly a risk that deserves to be noted.

5.7 Comparing the options

Formally, our analysis represents a partial cost-benefit analysis.⁶⁸ Some of the costs and benefits of the various options can be monetized, but others cannot.

⁶⁷ This assumption is not far-fetched. Mobile telephone handsets routinely do this today. Indeed, given that LTE (or something like it) is a candidate for the technical implementation of broadband PPDR (see Section 2.4.2), this capability might be quite easily achievable.

⁶⁸ See Section 9.1 of the Commission’s Impact Assessment Guidelines, 2009.

Consistent with standard practice for an Impact Assessment,⁶⁹ we begin by comparing the four options in terms of effectiveness, efficiency, and coherence. For purposes of this Impact Assessment, we define these terms as follows:

- **effectiveness** – the extent to which options achieve the objectives of the proposal.
- **efficiency** – the extent to which objectives can be achieved for a given level of resources/at least cost (cost-effectiveness).
- **coherence** – the extent to which options are coherent with the overarching policy objectives, and the extent to which they might have undesirable economic, social, or environmental consequences.

Relative to these criteria, it is clear that Option 1 (no change) has low effectiveness, inasmuch as it leaves high barriers in place to the deployment of new PPDR applications. Currently available spectrum, solely at national level in Germany, are insufficient to support deployment of most of these capabilities (see Section 3). Effectively, the productivity improvements associated with these enhancements are foregone.

In assessing the efficiency of Option 1, it is important to remember that we are speaking not of the efficiency of PPDR forces, but rather of the efficiency of achieving the objectives (which under this Option are not achieved). Thus, the efficiency effectively reflects the costs not incurred, in comparison with the potential benefits foregone. A new network is not built; no opportunity costs are relevant, because the spectrum in question is available for other uses; and no re-farming is required.

Phrased differently, the efficiency question effectively asks: Do the benefits of making this spectrum available really outweigh the costs? This is a crucial threshold question that cannot be avoided. Is it truly cost-justified to make the spectrum for these applications in the first place?

PPDR agencies in Germany are intent on deploying these capabilities in the years to come, so they are clearly already of the opinion that the costs of deploying the relevant networks (which they would directly bear) are less than the likely societal benefits.

Furthermore, it is likely that the longer term cost of operation of the new network, once the new network has evolved such that voice traffic can be consolidated with video and high speed data, is no greater than that of the current TETRA/Tetrapol network. There is, we suggest, no question that the benefits of current TETRA networks greatly exceed their costs of operation. Consequently, any incremental cost is a transitional issue for a limited number of years.

69 Ibid.

Thus, the more relevant question is whether the societal benefit, net of the cost of operating these networks, *exceeds the costs that these agencies do not bear*: the opportunity costs associated with the spectrum not being available for other uses, and the cost of re-farming the spectrum.

In comparison with Option 4, we find that the Option 1 is less expensive to the extent that it avoids the following costs:

- An opportunity cost of €60 million per MHz times 25 MHz below 1 GHz, plus €2 million times 27 MHz, for a total opportunity cost of €1,554 million.⁷⁰
- A re-farming cost of not more than €160 million.
- Incremental network operation costs for a limited number of years that, in comparison to the opportunity costs, are small enough to ignore.
- In round numbers, Option 4 is superior to Option 1 if it generates at least €1,714 million in net savings over the life of the system, which is surely at least thirty years.⁷¹

The cost could be justified by any combination of (1) lives saved, (2) property loss avoided, (3) gains in operational efficiency, and (4) avoidance of loss of life of PPDR personnel. In a simplistic calculation, the net savings must exceed €57 million per year. This is a modest threshold that will easily be exceeded by the gains associated with new PPDR capabilities.

Indeed, given the estimate of something approaching €1,500 million per year of natural disaster damage in Germany per year on average, a fairly modest improvement in the effectiveness of response could easily exceed this threshold. Similarly, in light of the number of crimes per year, and the societal cost per crime, improved effectiveness of crime prevention and deterrence (together with similar improvements for fire and emergency medical) likely exceed this threshold by a substantial margin.

An alternative view is that choosing Option 2, 3, or 4 is like an insurance policy – the potential costs of a major disaster or terrorist incident (including damage to the whole fabric of society) are so great that it is simply unthinkable not to make an investment of this magnitude. If the investment for Germany is on the order of say €1,700 million over a period of some thirty years, that is clearly the case.

⁷⁰ The opportunity cost associated with the 5150-5250 GHz band is assumed to be a sunk cost.

⁷¹ There are many different ways in which one could look at these numbers. One could compute an opportunity cost based on Net Present Value (NPV), or one could instead reason that the bidders at auction already reflected the NPV in their bid. One could factor in spectrum renewal costs, with the recognition that renewal is likely to happen sooner than obsolescence of the PPDR broadband system. Recognising that these estimates are rough, we choose instead to use a simple, understandable approximation.

Option 2 is presumed to provide sufficient spectrum to enable deployment of the new applications; however, there is some loss of price/performance of the equipment because of lack of standardisation of spectrum bands and technology. This is a factor, but perhaps not overwhelming by itself in Germany's case – Germany is big enough to benefit from its own economies of scale. The loss of potential savings might loom larger for smaller European countries.

Cooperation, both in terms of incidents at the border, and of the ability to loan PPDR forces from one European country to another, would clearly be problematic. Once a country fully incorporates broadband PPDR into its everyday procedures, it is likely that PPDR forces would find it difficult to operate without them.

Another dimension of efficiency, however, may be better in this case. Since spectrum is not harmonised under this Option, each European country is free to allocate spectrum that minimises country-specific opportunity costs and re-farming costs.

On balance, it seems reasonably clear that the losses of potential efficiency and interoperability are greater than any gains from increased allocation flexibility, which would necessarily be modest.

Options 3 and 4 are more or less equivalent in terms of effectiveness. Both permit a full deployment of new PPDR broadband applications based on high speed data and/or video capabilities, both achieve economies of scale and scope at European level, and both enable European PPDR forces to interoperate smoothly. They are also equivalent in terms of coherence.

These two options differ primarily in terms of efficiency. If we assume that air to ground coverage is 15 MHz in both scenarios, and that local access is 20 MHz, then the opportunity costs associated with spectrum allocation are more than twice as great for Option 3 as for Option 4. This difference is a direct reflection of the much higher opportunity cost for spectrum below 1 GHz (some €60 million per MHz) in comparison to the opportunity cost for spectrum above 1 GHz (some €2 million per MHz). These opportunity costs dominate the re-farming costs and any incremental network operation costs.

In terms of coherence, Option 1 is substantially inferior to the others in that it is less effective than the others in securing German (and by extension European) security, and thus entails economic, social and environmental risk. Option 2 is somewhat inferior to Options 3 and 4, inasmuch as it is less effective in enabling a coordinated response to an incident that affects more than one European country.

Table 5-7: Assessment of impacts against criteria

Criterion	Option 1: No change	Option 2: Let a thousand flowers bloom	Option 3: Harmonised solution below 1 GHz	Option 4: Harmonised solution below 1 GHz and above 1 GHz
Effectiveness	Low. In the absence of additional spectrum, new applications that depend on video and high speed data cannot be deployed.	Moderate. New applications can be deployed, but cross border interoperability is not assured, nor the ability to loan PPDR forces to other countries.	High. New applications can be deployed, cross border interoperability is assured, and PPDR forces from one country can be fully effective operating in another.	High. New applications can be deployed, cross border interoperability is assured, and PPDR forces from one country can be fully effective operating in another.
Efficiency	Low. This is the lowest cost option, but it fails to achieve the quite substantial benefits that new PPDR technology potentially offer.	Low. Achieves the benefits of new PPDR applications, but fails to achieve economies of scale or scope. Certain costs are low, but the overall relationship of costs to benefits is poor.	High. Achieves all benefits but opportunity costs may be excessive.	Highest. Achieves all benefits, and has lower opportunity and re-farming costs than Option 3.
Coherence	Low, in the sense that it fails to promote security, counter-terrorism, or law enforcement.	Moderate, in the sense that it promotes security, counter-terrorism, and law enforcement, but not in a way that enhances international cooperation.	High, in the sense that it promotes security, counter-terrorism, and law enforcement in ways that enhance international cooperation.	High, in the sense that it promotes security, counter-terrorism, and law enforcement in ways that enhance international cooperation.

Taking into account the qualitative factors noted in Table 5-7, together with the quantitative comparisons from this section and the previous, it is clear that Option 4 should be preferred.

5.8 Monitoring and evaluation

An impact assessment routinely identifies a plan for monitoring and evaluating the results of the proposed action; however, we think in this case that there is no point in being highly specific at this time. The German Ministry of Economics and Technology (BMWi) should monitor and assess progress if it chooses to proceed with Option 4; however, Option 4 implies action at European level. Germany can influence these actions, but does not uniquely control any of them.

6 Findings and recommendations

Section 6.1 presents our key findings, while section 6.2 provides recommendations to the German Ministry of Economics and Technology (BMWi).

6.1 Findings

The section provides our key findings in regard to the spectrum needs of the public safety community for broadband mobile communications over the period 2015 – 2025, based on anticipated user needs and technology developments, and on certain of the possible costs associated with satisfying those needs.

Section 6.1.1 summarises our findings in regard to German PPDR spectrum requirements. Section 6.1.2 provides general remarks as to how these might relate to PPDR spectrum requirements in other European countries. Section 6.1.3 reviews key findings in regard to costs and benefits.

6.1.1 PPDR Spectrum to support German needs

This section provides our findings in regard to German PPDR spectrum needs. It summarises the results of Section 2.4.

6.1.1.1 Spectrum to support Wide Area Mobile Broadband Communications

Assuming that one of the IMT-Advanced technologies recognised by the ITU such as LTE Advanced or Mobile WiMAX is deployed, we estimate that the minimum spectrum requirements will be:

- Uplink: 15 MHz
- Downlink: 10 MHz

In order to provide optimum coverage and to keep the required number of cells to a manageable level (and to enable building penetration when needed), frequencies below 1 GHz should be used. The dominant driver of spectrum demand in the wide area network is to be able to handle an incident that occurs at the edge of the cell coverage area, and the spectrum requirement is substantially unaffected by the presence of additional incidents elsewhere in the cell, because of the higher spectrum efficiency that exists away from the cell edge.

6.1.1.2 Spectrum to support Local Area Mobile Broadband Communications

Our analysis indicates that the spectrum already identified for public safety use in the 5150 - 5250 MHz band will be adequate to cater for most capacity “hot spots” arising from major events or incidents in Germany. Existing 802.11 based technology could be

deployed in this band, taking advantage of the higher power level permitted for public safety use; alternatively, ad hoc mesh networks could be considered, or LTE picocells and repeaters.

If feasible, this spectrum could be augmented with other spectrum above 1 GHz. We view the 1452 - 1479 MHz band as a promising candidate.

6.1.1.3 Spectrum to support air to ground links

We estimate that a minimum 15 MHz (unpaired) in the range 1 - 5 GHz is required on a harmonised European basis to support air to ground video links, with potentially a further 7.5 MHz required to meet Germany-specific requirements, based on our understanding of the requirements from the IABG report. Coordination with the military could be considered.

6.1.1.4 Spectrum for Backhaul

We believe that backhaul requirements for the wide area network can be met from existing microwave fixed link bands. It should not be necessary to reserve specific spectrum for public safety applications. Higher frequency fixed link bands such as 33 GHz or 58 GHz could also be used to support fixed installations such as CCTV surveillance, in preference to using scarce mobile spectrum.

6.1.2 PPDR spectrum requirements in other countries

We anticipate that other European countries will want to conduct their own assessments, based on their respective needs and national circumstances.

Few European countries have analysed their needs to date. A study of Norwegian PPDR needs suggests that they are broadly similar to those of Germany. The input of the French ANFR appears in full in Section 4.5.

Our estimate of spectrum required for wide area needs (15 MHz uplink and 10 MHz down) is likely to be broadly applicable to other European countries, *to the extent that their application requirements are similar to those of Germany*. The spectrum requirements are largely driven by the need to address incidents that occur at the edge of the cell coverage area, and will thus tend to be largely independent of the size or population of a European country.

The finding that the 5150 - 5250 MHz, augmented if possible with spectrum from the 1452 - 1479 MHz band, is likely to be adequate to deal with most local “hot spots” is also likely to be relevant to most if not all European countries.

For air to ground links, 15 MHz in the range 1 - 5 GHz may be adequate for other European countries.

We anticipate that most if not all European countries will find that they can meet wireless backhaul requirements from existing microwave fixed link bands.

6.1.3 Costs and Benefits

As it happens, costs are easier to quantify than benefits. Benefits are, however, quite substantial, and in our view outweigh the costs by a substantial margin.

6.1.3.1 Benefits of new broadband wireless PPDR applications

Quantifying the benefits of additional PPDR spectrum is challenging, but the benefits are sure to be substantial.

Benefits could be expected to flow from multiple factors:

- **Reduced risk of loss of life:** Based on an extensive literature, one can reasonably claim that saving a life has a monetary value of at least €2 to €10 million, leaving aside for a moment the obvious societal benefits (see Section 5.6.2.1). Enhanced PPDR communications should save lives in day to day usage and in disasters. Publicly available statistics suggest that better disaster preparedness has played a huge role in reducing loss of life over the past century, and will presumably continue to do so, so it is reasonable to assume that these savings would be real and substantial (see Section 5.6.2.1.4).
- **Reduced risk of property damage:** Property damage should also be reduced, both in day to day operations and in the event of disasters. Statistics show a substantial *increase* in property damage due to disasters throughout the past century (see Section 5.6.2.1.4), despite improvements in preparedness. It is unclear whether this increase reflects improved reporting, an increase in the severity of the disasters themselves, or an increase in the value of property that is potentially in harm's way. In any event, better PPDR communications should result in a more effective response, and thus in reduced risk to property.
- **Productivity improvements for the PPDR activity:** PPDR providers should be able to achieve better protection at the same price, or comparable protection at a lower price.
- **Reduced risk of injury or death for PPDR forces:** Improved tools can be expected to reduce the personal risk at which Germany places its PPDR professionals.

6.1.3.2 Benefits of harmonising the broadband PPDR spectrum allocation

As noted elsewhere, the key benefits that a *harmonised* spectrum allocation for PPDR broadband can reasonably be expected to achieve, in conjunction with appropriate protocol and equipment standardisation, include:

- **Better price/performance** for broadband PPDR equipment and services, thanks to economies of scale and scope.
- **Enhanced cross-border PPDR cooperation** in responding to incidents that involve more than one European country.
- **Ability to lend PPDR forces from one European country to another** where an incident or disaster exceeds the capacity of one European country to respond, or where specialised skills that not every European country possesses are needed to respond to a particular threat, incident or disaster. Once these new PPDR capabilities are available, they will be incorporated into the *Standard Operating Procedures (SOP)* of PPDR forces. If PPDR forces are unable to follow their SOP while on loan to another country, their effectiveness and efficiency stand to be substantially impaired.

6.1.3.3 Opportunity costs

To an economist, an *opportunity cost* is the cost of not doing something that otherwise could have been done. In the current context, the opportunity cost associated with allocating spectrum for use by PPDR would be the societal value that could have been gained had the spectrum instead been used for mobile services, or broadcast television, or some other socially meritorious purpose. How much potential value to society would be sacrificed?

Spectrum allocations to a broad form of use are generally made by regulators, often at an international or global level, but spectrum assignments of commercial spectrum to a single organisation are often done these days using commercial mechanisms such as auctions, trades or leases. These commercial mechanisms are meant to ensure that commercial users are constantly confronted with the opportunity cost associated with holding their spectrum, and are thus motivated to put spectrum to its highest valued potential use.

The price paid at auction can generally be assumed to be a reasonably good indication of a spectrum block's real value, assuming that the buyers are knowledgeable and that the auction is not subject to arbitrary constraints. Given that Germany recently conducted a large spectrum auction that is relevant to bands close to those which would be most suitable for broadband PPDR use, a basis for estimating the opportunity cost is readily at hand. The value of the 800 MHz spectrum in Germany's recent spectrum

auctions is a reasonably good proxy, in our view, for the opportunity cost of allocating spectrum under 1 GHz to PPDR broadband use in Germany. With that in mind, we use €60 million per MHz as an estimate of the opportunity cost of allocating spectrum under 1 GHz to PPDR, and €2 million per MHz as an estimate of the opportunity cost of allocating spectrum above 1 GHz to PPDR (see Section 5.6.2.2).

The opportunity cost associated with Germany's allocation of a pair of sub-1 GHz bands totalling 25 MHz to PPDR would thus be some €1,500 million.

If one were to assume that the opportunity cost is proportional to population, and noting that the EU-27 as a whole is 6.13 times as populous as Germany, one might assume a total opportunity cost for the EU-27 in the general range of some €9,200 million.

6.1.3.4 Re-farming costs

Re-farming costs for the sub-1 GHz spectrum would, of course, be heavily dependent on the specific pair of bands that were ultimately selected, and the frequencies to which the applications were to be relocated. Nonetheless, it is reasonable to assume that, *other things being equal*, costs will tend to be very roughly proportional to (1) the size of the band, in MHz, and (2) the number of individuals potentially covered by the network.

Experience with relocation of military and broadcasting bands in France over the past decade has demonstrated re-farming costs ranging from €0.001 to €0.02 per MHz/POP, while US experience with relocation of military and civilian agencies in the 1710 - 1755 MHz band reflects a cost of €0.05 per MHz/POP (see Section 5.6.2.3).

If the cost of relocating existing spectrum users is assumed to be roughly €0.001 (low), €0.02 (moderate), or €0.05 (high) per MHz/POP, consistent with French and US experience, then the total cost of clearing a 25 MHz band in Germany (with an estimated population of some 81,757,600 as of 1 January 2010⁷²) could be assumed to be €2 million (low), €41 million (moderate), or €102 million (high).

The equivalent estimate for the EU-27, based on a population of 501,259,800,⁷³ would be €13 million (low), €251 million (moderate), or €627 million (high).

6.1.3.5 Network construction and operating costs

We have not attempted to estimate network capital or operating expense. Based on the interviews conducted by IABG, it is clear that German PPDR staff believe that benefits are well in excess of any foreseeable capital or operational costs.

⁷² Euorstat, Giampaolo LANZIERI, "Population and social conditions: First demographic estimates for 2009", Data in focus 47/2009, available at: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-QA-09-047/EN/KS-QA-09-047-EN.PDF.

⁷³ Ibid.

6.2 Recommendations

This report is on behalf of the German Ministry of Economics and Technology (BMWi); however, many of the actions proposed need to be undertaken at European level. Therefore, these recommendations are formulated in terms of steps that the German Ministry of Economics and Technology (BMWi) might take, ideally with the support of the German Ministry of the Interior (BMI) and the German Federal Network Agency (BNetzA), to promote a solution that is consistent with German interests.

Other European governments may wish to consider these recommendations in terms of their respective needs and circumstances.

Section 6.3 summarises core ideas for the way forward in terms of spectrum allocations. Section 6.3.1 provides complementary recommendations in regard to equipment and protocol standardisation. Finally, Section 6.3.2 urges the BMWi to seek to achieve implementation through interaction with a wide array of other stakeholders.

A summary of the Recommendations, together with the number of the page on which each appears, follows.

Recommendation 1. German policy should advocate a harmonised allocation with two sub-bands below 1 GHz: one of 15 MHz (uplink) and one of 10 MHz (downlink).	106
Recommendation 2. Continued use of the and 5150 - 5250 MHz band for local PPDR, augmented if feasible by the use of the 1452 - 1479 MHz band.	106
Recommendation 3. Promote a 15 MHz harmonised air to ground allocation.	106
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Recommendation 5. Promote development of standards that enable seamless interoperability.	107
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6.3 The way forward

This study confirms what the German Ministry of Economics and Technology has long assumed: *Germany interests in regard to spectrum for broadband PPDR are best addressed by means of a solution that is somehow harmonised at European level.*

In broad outline, and based on the Germany-specific Impact Assessment that appears in Section 5.3 of this report, we believe that the best solution for Germany would be characterised by the following approach (which was identified as Option 4 in Section 5.5).

Option 4: Harmonised solution in one or more bands or tuning ranges below 1 GHz, plus one or more bands or tuning ranges above 1 GHz
<ul style="list-style-type: none"> • Lower bands or tuning ranges to meet requirements for coverage and building penetration • Upper bands or tuning ranges to satisfy requirements for capacity / surges • National augmentation of harmonised bands permitted within predefined tuning ranges • Continued use of spectrum in 380-400 MHz range (not necessarily contiguous with the new bands) for TETRA/TETRAPOL

We would encourage other European countries to consider these findings relative to their respective national circumstances. We believe that our assessment will be found to be broadly applicable, and are of the view that Option 4 should be the preferred option in other European countries as well.

This approach assumes that capacity for peak use (major concerts and sporting events) and disasters will be achieved by deploying an ad-hoc wireless local area network connected to a relay station, either mounted in a truck or deployed with a command post, to relay communications using either wired facilities or a wireless link with a directional antenna. In very remote locations a temporary satellite link may need to be deployed.

The recommendation is written in terms of dedicated spectrum, but this dedicated PPDR spectrum should be supplemented or supplanted where feasible (within

constraints for capacity and reliability) with (1) applications using commercial services and commercial spectrum, and (2) spectrum shared with other users and uses.

Detailed German spectrum needs for broadband PPDR were assessed in Section 2.4. Key findings are summarised in Section 6.1.1 of this report.

We believe that Germany's needs can be satisfactorily met with two bands below 1 GHz: one of 15 MHz uplink and one of 10 MHz downlink in order to enable nationwide coverage (including building penetration), complemented by the use of the 5150 - 5250 MHz band and if practical the 14 in order to achieve the extra capacity needed for peaks and disasters.

Recommendation 1. German policy should advocate a harmonised allocation with two sub-bands below 1 GHz: one of 15 MHz (uplink) and one of 10 MHz (downlink).

German policy should advocate a harmonised solution with two sub-bands below 1 GHz: one of 15 MHz (uplink) and one of 10 MHz (downlink).

In addition, German policy should seek to ensure that the 5150 - 5250 MHz band continues to be available on a harmonised basis for PPDR. Germany should seek to promote an additional 15 MHz harmonised allocation in the range 1 - 5 GHz, possibly coordinated with the military, for air to ground usage. Recognising that Germany, like many European countries, has some regions that would be difficult to reach at reasonable cost with a terrestrial network, Germany should promote solutions that that an integrated and appropriate view of the use of satellites (promoting as much interoperability as might prove to be feasible). Finally, Germany need not seek additional allocations for wireless backhaul, inasmuch as existing fixed link allocations appear to be adequate.

Recommendation 2. Continued use of the and 5150 - 5250 MHz band for local PPDR, augmented if feasible by the use of the 1452 - 1479 MHz band.

German policy should reflect continued use of the 5150 - 5250 MHz band for local PPDR, augmented by the use of the 1452 - 1479 MHz band, to optimise coverage and capacity at major incidents.

Recommendation 3. Promote a 15 MHz harmonised air to ground allocation.

Germany should promote an additional 15 MHz harmonised allocation in the range 1 - 5 GHz, possibly coordinated with the military, for air to ground usage.

Recommendation 4. Take an integrated view toward the use of satellite, primarily for areas that are hard to reach with terrestrial networks.

Make use of satellite platforms (fixed and mobile) in areas beyond the reach of terrestrial networks.

6.3.1 Spectrum and technology recommendations

Whatever technological standards are chosen, we would note that the following characteristics are highly desirable, if not absolutely essential:

- **Full interoperability:** Systems from different vendors, or procured for different European countries, should be able to interoperate at some predetermined level without any modifications or special arrangements.
- **Economies of scale:** If technically feasible, equipment should be designed such that PPDR-specific capability is layered on top of an existing technology such as LTE or WiMAX (or 802.11 for wireless LAN PPDR). Doing so potentially enables the equipment to benefit from mass market economies of scale (e.g. in chipsets), and possibly to interoperate with commercial networks (perhaps with reduced functionality).

Recommendation 5. Promote development of standards that enable seamless interoperability.

Germany should, through its interactions with other stakeholders, promote the development of technical standards for equipment and protocols that ensure full, seamless interoperability of broadband PPDR solutions.

Recommendation 6. Promote full compliance with standards that seek to ensure interoperability.

Germany should, through its interactions with other stakeholders and through its procurement policies, promote full compliance with technical standards for equipment and protocols that seek to ensure full, seamless interoperability of broadband PPDR solutions.

6.3.2 Engagement with other stakeholders

The German government cannot unilaterally achieve a shared allocation that meets these requirements, but it can use its good offices to foster an informed consensus. Germany's interests in this matter will tend to be aligned with those of most if not all European countries, and of many other stakeholders as well.

For these reasons, our report encourages the German government to engage closely with a wide range of stakeholders in order to obtain a positive resolution to the matters discussed in this report.

6.3.2.1 Other European Countries

We know of no European country that has not recognised the need going forward to ensure that spectrum allocations can enable the deployment and use of new PPDR applications that depend on high speed data and/or video.

German PPDR spectrum requirements may, however, be greater than those of many of its neighbours. This reflects not only the fact that Germany is a large country with substantial PPDR forces, but also the fact that Germany intends to make extensive use of new PPDR technology.

This suggests that most European countries will agree with Germany on the need for a harmonised allocation for PPDR spectrum, but not all will agree with Germany as to how much spectrum is needed.

With this in mind, Germany should prefer technical solutions that provide full interoperability, but that also provide European countries with some flexibility to tailor the size of the PPDR spectrum allocation to meet their respective national circumstances. For allocations above 1 GHz, since they are intended to provide additional “burst” capacity in the event of a peak event or a disaster, each European country could have some latitude as to which of these bands to allocate, and how much spectrum to allocate in each potential band. For the sub-1 GHz allocation, it is probably simplest in the interest of full interoperability to have a single band or tuning range, but there might be some flexibility as to how large the band should be. In all cases, the equipment and associated protocols and mechanisms need to be able to dynamically figure out what spectrum can be used in the country in which the equipment finds itself.

This might sound complicated, but in reality it is what mobile telephones routinely do today.

Recommendation 7. Work with other European countries to seek consensus.

The German Ministry of Economics and Technology should seek constructive dialogue with other European countries in order to identify areas of agreement and to attempt to forge a consensus going forward.

Recommendation 8. Be prepared to accept solutions that enable other countries to tailor the size of spectrum allocations to their individual circumstances, as long as full interoperability can be maintained.

In the interest of achieving consensus, the German Ministry of Economics and Technology should give due consideration to technical approaches that enable

different European countries to allocate different amounts of spectrum to broadband PPDR, while ensuring that any country-specific spectrum allocations are automatically recognised and that full interoperability is maintained.

6.3.2.2 Other European and global stakeholders

Without further elaborating, we have made the following recommendations to the Germany Ministry of Economics and Technology:

Recommendation 9. Continue to work with CEPT/ECC, and particularly with PT 38, to achieve consensus.

The German Ministry of Economics and Technology should continue to be engaged with CEPT/ECC, and particularly with PT 38, in order to identify areas of agreement and to attempt to forge a consensus going forward.

Recommendation 10. Continue to work with the European Commission and with the Radio Spectrum Committee (RSC).

The German Ministry of Economics and Technology should continue to be engaged with the European Commission, with the Radio Spectrum Committee (RSC), and with other European Union institutions in order to identify areas of agreement and to invite the Commission to promote harmonised allocations in support of broadband PPDR.

Recommendation 11. Engage with ETSI to ensure that it brings its work to a timely conclusion, while ensuring full interoperability, automatic recognition of country-specific bands, and the possibility of using standard protocol chipsets.

The German Ministry of Economics and Technology should continue to be engaged with ETSI in order to encourage it (1) to bring its work to a timely conclusion, (2) to ensure that broadband PPDR solutions are fully interoperable, (3) to ensure that broadband PPDR equipment can deal automatically with the possibility that not every country will implement exactly the same broadband PPDR spectrum bands, and (4) to consider structuring its broadband PPDR solutions in such a way that the use of standard chipsets is not needlessly precluded.

Recommendation 12. Continue to monitor international developments.

For now, the German Ministry of Economics and Technology should continue to monitor international developments, but should not rely on any of them coming to fruition.

Recommendation 13. Work with the broadcasting community.

The German Ministry of Economics and Technology should maintain a dialogue with the broadcasting community in order to identify areas of agreement and to explore solutions going forward.

Recommendation 14. Work with NATO.

The German Ministry of Economics and Technology should continue to engage with NATO in order to identify any possible areas of agreement, and to explore the possibility of a mutually agreeable arrangement regarding spectrum for broadband PPDR going forward.