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Final Report

The need for PPDR Broadband Spectrum in the bands below 1 GHz

for the
TETRA + Critical Communication Association
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1 Introduction

The need for spectrum suitable for the support of emerging broadband applications for Public Protection and Disaster Relief (PPDR) has been recognised for many years. The public safety community is well aware of these needs. Numerous studies have overwhelmingly substantiated these requirements, including several in which this author had the honour to participate.[1]

This same body of research and analysis has also consistently shown that existing PPDR communications technology and spectrum will not be sufficient for future PPDR broadband needs. The *TETRA (Terrestrial Trunked Radio)* and *TETRAPOL* networks that are now deploying or deployed in Europe are a good solution for mission critical voice and for narrowband data (up to 28 kbps); however, capacity for broadband data is too limited, especially as needs for video grow (including video reporting from field locations, and from helmet and drone cameras). There are plans to upgrade to a so-called wideband solution for TETRA networks known as the *TETRA Enhanced Data System (TEDS)*; however, this upgrade must be viewed as a short term palliative. TEDS will still be limited to speeds of less than 200 Kbps, which is an order of magnitude less than even the medium term needs for PPDR broadband as identified by multiple studies, or the capabilities of existing 3G mobile networks.

Meeting these needs is challenging, to say the least. The ideal spectrum for PPDR is the same sub-1 GHz spectrum that is already used extensively by the military and the broadcasting industry, and that is highly sought by the commercial mobile industry. It is valuable to all of these segments for largely the same reasons: a low cost means of achieving coverage, and good building penetration characteristics.

Meanwhile, there has been a clear recognition of the need for concerted action on broadband PPDR spectrum at least at European level, if not at global level. There are a number of recognised benefits that tend to arise from the harmonisation of a suitable spectrum tuning range (or, better yet, a specific band), all of which are highly relevant to PPDR. These benefits include:

1 See for instance Kenneth Carter and Val Jervis (2007), “Safety First”; J. Scott Marcus et al. (2008), “Optimising the Public Sector’s Use of the Radio Spectrum in the European Union”; Fritsche, Wolfgang/Mayer, Karl (20 Mai 2010): Studie zum mittel und langfristigen Kapazitätsbedarf der BOS in der drahtlosen Kommunikation, IABG; J Scott Marcus and John Burns et al. (2010): “PPDR Spectrum Harmonisation in Germany, Europe and Globally”; Hans Borgonjen (2011), “LEWP RCEG mobile data applications matrix”, CEPT LEWP-RCEG; and most recently Matti Peltola (2013), “Evolution of the Public Safety and Security Mobile Networks”, *Communications & Strategies*. Outside of Europe, see the various reports noted in the References at the end of this paper, notably including John Ure (2013), “Public Protection and Disaster Relief (PPDR) Services and Broadband in Asia and the Pacific: A Study of Value and Opportunity Cost in the Assignment of Radio Spectrum”, June 2013, and from the US, NPSTC, Public Safety Communications Assessment 2012-2022: Technology, Operations, & Spectrum Roadmap, Final Report, 5 June 2012.

- Economies of scale in terms of production, and also in terms of staff training, together with the network effects benefits that flow from expanded equipment availability;
- Interoperability of equipment between different PPDR teams within a country;
- Interoperability of equipment for incidents that involve multiple countries (either because they occur at a border, or because they are geographically large); and
- The ability to seamlessly loan PPDR teams from one country to another in times of need, whether the emergency strikes in a border area or not.

As we explain shortly, the need for harmonised action has been recognised by the public safety community,[2] and also by the European Commission in the Radio Spectrum Policy Program (RSPP).[3]

The need for coordinated action is paramount, but the action itself has been limited or lacking to date. This short study is inspired by the recognition that the issue has become ripe. Concerted action is needed due to:

- Ongoing auctions in the 800 MHz band; and
- The 2012 *World Radiocommunication Conference (WRC)* decision to reallocate the 700 MHz band to include mobile services (which includes mobile broadband), immediately following the 2015 WRC.

In this discussion paper, we (1) briefly review what is known about the spectrum needs for PPDR; (2) identify what is known about costs and benefits of a harmonised allocation for broadband PPDR spectrum; (3) summarise the challenges in finding spectrum below 1 GHz; (4) explain why auctions do not properly reflect the societal value of PPDR spectrum; (5) consider options for shared use between PPDR and

2 The organisations responsible for PPDR are convinced that their needs for mission critical broadband services can only be met by dedicated harmonised spectrum. See for instance TCCA (2013), Future Broadband Spectrum needs for PPDR: Communiqué from Roundtable discussion, 23 May 2013. “The PPDR user and operator representatives [at the London meeting] supported the view that it is essential for governments’ organisations to control enough dedicated and harmonised spectrum in order for their organisations to deliver service to society. … The meeting could also conclude that there is now unanimous support from the PPDR users and operators to seek such spectrum as part of the World Radio Conference in 2015.”

3 See especially paragraph 32 in the recitals of the RSPP, which recognises the need for free movement of public safety services and devices, and acknowledges the studies that have identified the need for additional spectrum for PPDR spectrum under 1 GHz within the EU within the next five to ten years. See also Article 8(3), which says in part: “The Commission shall, in cooperation with the Member States, seek to ensure that sufficient spectrum is made available under harmonised conditions to support the development of safety services and the free circulation of related devices as well as the development of innovative interoperable solutions for public safety and protection, civil protection and disaster relief.” Note that this article calls for the identification of spectrum “under harmonised conditions”, not necessarily for establishment of a fully harmonised band or bands.

commercial LTE-based mobile network operators (MNOs); and (6) make suggestions for policy going forward.

2 Public safety broadband applications and their requirements

The drivers for increased bandwidth, and thus for increased availability of spectrum, for public safety mobile broadband are numerous and complex.

Public protection and disaster relief (PPDR) is the general designation given to a range of public safety services. Informally, they consist primarily of police, fire and emergency medical services. Also included within the ambit of PPDR are search and rescue, border security, event security, protection of VIPs and dignitaries, evacuation of citizens, and other aspects of the response to natural and man-made disasters.

The formal definitions of PPDR derive from Report ITU-R M.2033 “Radiocommunication objectives and requirements for public protection and disaster relief”:

- **Public protection (PP) radiocommunication:** Radiocommunications used by responsible agencies and organisations dealing with maintenance of law and order, protection of life and property, and emergency situations.
- **Disaster relief (DR) radiocommunication:** Radiocommunications used by agencies and organisations dealing with a serious disruption of the functioning of society, posing a significant, widespread threat to human life, health, property or the environment, whether caused by accident, nature or human activity, and whether developing suddenly or as a result of complex, long-term processes.

A harmonised pair of bands at 380-385 and 390-395, nestled within the NATO bands, has been in use in Europe since 1996 for PPDR *voice and narrowband communication* based on TETRA and TETRAPOL standards. These voice arrangements typically provide functionalities that differ from conventional mobile services (group call, direct mode operation). In practice, it took many years for the corresponding networks to be built out, but at this point deployment is substantial.

Existing harmonised PPDR arrangements do not, however, address emerging needs for *broadband* PPDR data, even though the need has been recognised for many years.[4]

In Section 2.1, we describe PPDR applications and summarise their functional requirements; in Section 2.2, we review the bandwidth and corresponding spectrum requirements that flow from those functional requirements.

2.1 PPDR applications and associated functional requirements

It has long been felt that existing or planned narrowband and wideband PPDR spectrum and technology would not suffice for truly broadband applications including database

4 It was already evident at the time of our 2008 study for the European Commission. See J. Scott Marcus, John Burns, Phillipa Marks, Frédéric Pujol, and senior expert Prof. Martin Cave (2008), “Optimising the Public Sector’s Use of the Radio Spectrum in the European Union”.

access, robotics control, and especially video from the field to headquarters. Increased interest in video from drone vehicles (including UAVs) and person worn cameras (e.g. helmets) has provided a particularly strong motivation for increased bandwidth. A wide range of additional broadband applications for PPDR are also anticipated.

A number of studies have identified and characterised PPDR applications.[5] An important recent reference is the Requirements Matrix that was agreed by the Radio Communications Expert Group (RCEG) of the Law Enforcement Working Party (LEWP),[6] a copy of which appears as an Annex to ECC Report 199. The Report also provides helpful use cases.

The RCEG/LEWP matrix assesses some fifty applications in terms of a range of key parameters including (1) throughput required, (2) number of users, (3) frequency of use per month per user, (4) whether use is necessarily mobile, (5) whether continuous operational availability is mandatory (i.e. the degree to which the application is mission-critical), and the stringency of security and privacy requirements.

Nine of the applications entail video in one form or another, which is perhaps not surprising. Other applications entail download of (annotated) maps and other data from Geographic Information Systems (GIS) (and upload when needed), patient monitoring data, data on the condition of the PPDR worker (pulse, stress level, carbon monoxide, and so on), upload of biometric data (e.g. fingerprints), and a range of tracking and location services.

The applications are highly diverse. Most are important to the protection of property and the safety of human life. Some are also crucial to the safety of PPDR personnel.

Food for thought 1: Using robots to disarm unexploded bombs in Germany[7]

… This explosive wartime legacy poses the biggest threat to bomb disposal specialists, 11 of whom have been killed during clearance missions since 2000. In June 2010, three men died in one explosion in the central German city of Göttingen. The plan was to defuse a 500-kilogram bomb with a delayed-action detonator that was discovered on the Schützenplatz, a popular central location for antique and flea markets. One hour before

5 In addition to the sources identified later in this paragraph, see J. Scott Marcus et al. (2008), “Optimising the Public Sector’s Use of the Radio Spectrum in the European Union”; Fritsche, Wolfgang/Mayer, Karl (20 May 2010): Studie zum mittel und langfristigen Kapazitätsbedarf der BOS in der drahtlosen Kommunikation, IABG; J Scott Marcus, John Burns et al. (2010): “PPDR Spectrum Harmonisation in Germany, Europe and Globally”; John Ure (2013), “Public Protection and Disaster Relief (PPDR) Services and Broadband in Asia and the Pacific: A Study of Value and Opportunity Cost in the Assignment of Radio Spectrum”, June 2013; and US NPSTC, Public Safety Communications Assessment 2012-2022: Technology, Operations, & Spectrum Roadmap, Final Report, 5 June 2012.

6 The Radio Communications Expert Group (RCEG) of the Law Enforcement Working Party (LEWP) officially reports to JHA (Justice and Home Affairs) within the Council of the European Union.

7 Carsten Holm (2012), 'Sitting on a Powder Keg': Germany's WWII Duds Get Deadlier, Die Spiegel, 3 October 2012.

the planned use of the robot, the bomb exploded even though none of the technicians were touching it.

"When working with bombs with delayed-action detonators, you're not even allowed to cough heavily, that's how sensitive they are," says Horst Reinhardt, technical director of the bomb disposal squad in the town of Wünsdorf in the eastern German state of Brandenburg. Reinhardt has personally defused some 150 bombs. Is he afraid of these operations? "No," he says, "my wife fears for my safety. But for me, it's just routine." …

Drawing on the RCEG-LEWP analysis, the CEPT ECC assessment of PPDR spectrum identifies a number of valuable broadband applications, including:

- High resolution video communications from wireless clip-on cameras to a vehicle mounted laptop computer, used during traffic stops or responses to other incidents.
- Video surveillance of security entry points such as airports with automatic detection based on reference images, hazardous material or other relevant parameters.
- Remote monitoring of patients. The remote real time video view of the patient can demand up to 1 Mbps. This demand for capacity can easily be envisioned during the rescue operation following a major disaster. This may equate to a net capacity of over 100 Mbps.
- High resolution real time video from, and remote monitoring of, fire fighters in a burning building.
- The ability to transmit building plans to the rescue forces.

Food for thought 2: Person worn video and location services could save lives[8]

For 33 minutes on June 30, as 19 members of an elite firefighting crew known as the Granite Mountain Hotshots marched through a burning forest south of this city in central Arizona, no one knew for sure where they were or why they had descended from the ridge they had been traveling and onto a basin where they would die. …

Juliann Ashcraft, whose husband, Andrew, … lost his life, said she walked away wondering what, if anything, would be done to prevent a similar tragedy. "Why didn't they have more technology on them, something to tell where they were," she asked, "more eyes and ears?"

8 Fernanda Santos (2013), Report Cites Poor Communication Before Firefighters' Deaths in June, New York Times, 28 September 2013.

CEPT ECC Report 199 goes on to summarise broadband and wideband applications as shown in Table 1. Wideband applications may not absolutely require broadband capabilities, but they surely benefit from them.

Table 1: Wideband and broadband PPDR applications

Application	Feature	PPDR Example
Wideband *Messages* *Data Talk around / direct mode operation* *Database interaction (medium record size)*		
	E-mail possibly with attachments	*Routine e-mail message*
	Direct unit to unit communication without additional infrastructure	*Direct handset to handset, on-scene localised communications*
	Forms and records query	*Accessing medical records*
	Instantaneous access to voice path	*Lists of identified person/missing person*
	Security	*GIS (geographical information systems)*
Text file transfer	*Data transfer*	*Filing report from scene of incident*
	One-to-many (broadcasting)	*Records management system information on offenders*
Image transfer		*Downloading legislative information*
	Download/upload of compressed still images	*Biometrics (finger prints)*
		ID picture
Telemetry Security		*Building layout maps*
	Location status and sensory data Priority access	Vehicle status
		Critical care
Video	Download/upload compressed video	Video clips
	Forms based incident report	Patient monitoring (may require dedicated link)
		Video feed of in-progress incident
Interactive	Location determination	2-way system
		Interactive location data
Broadband Database access	Intranet/Internet access Web browsing	
		Accessing architectural plans of buildings, location of hazardous materials
		Browsing directory of PPDR organisation for phone number
Robotics control Video	Remote control of robotic devices Video streaming, live video feed	Bomb retrieval robots, imaging/video robots
		Video communications from wireless clip-on cameras used by in building fire rescue
		Image or video to assist remote medical support
Imagery	High resolution imagery	Surveillance of incident scene by fixed or remote controlled robotic devices
		Assessment of fire/flood scenes from airborne platforms
		Downloading Earth exploration-satellite images

In a recent study of broadband PPDR requirements in six Asia-Pacific countries,[9] John Ure interviewed PPDR community stakeholders to assess the degree to which broadband was viewed as being important or essential going forward (see Table 2). The respondents included emergency medical, police, fire, and civil defence staff, as well as Spectrum Management Authorities.

The results are striking. Broadband is viewed as valuable for all PPDR radio communication services, even e-mail. Some, including videoconferencing, video streaming of real time images, high quality transmission of images, and digital mapping of locations are hard to imagine without broadband transmission capabilities.

9 John Ure (2013), "Public Protection and Disaster Relief (PPDR) Services and Broadband in Asia and the Pacific: A Study of Value and Opportunity Cost in the Assignment of Radio Spectrum", June 2013.

Table 2: PPDR stakeholder perceptions of the importance of broadband

Type of Service	Narrowband sufficient	Broadband Desirable	Broadband Required
1. Video conferencing	*1*	*3*	*5*
2. Video streaming of real-time images such as from CCTV on scene or attached to patrol cars back to the control centre and to devices in the field			*6*
3. Video streaming of non-real-time images such as from CCTV on scene or attached to patrol cars back to the control centre and to devices in the field		*2*	*4*
4. 3-D video forensics		*2*	*2*
5. *Improved* data transfers such as vital medical statistics, causality numbers, hazard information, etc.		*3*	*4*
6. Full email	*1*	*5*	
7. *High quality* transfers of images such as facial recognition, number plate recognition, building diagrams, remote borders, etc.		*1*	*5*
8. Digital mapping of locations		*2*	*5*
9. Remote database access		*5*	*2*
10. Sensor device network communications (M2M)		*4*	*2*
11. Telemetry and remotely controlled devices, such as robots to enter hazardous areas, helmet cameras, air-flying drones, etc.		*3*	*3*
12. Internet browsing	*1*	*5*	*1*
13. Ability of move the back office into the field		*6*	*1*
14. *Improved* OTA (over-the-air) ability to download software applications and upgrades on the spot		*5*	
15. *Reception* of satellite images		*5*	*2*
16. Locating spots - GPS	*1*	*5*	
17. Other (please specify)			

In the United States, the NPSTC has also analysed a range of use cases, and has identified extensive needs and opportunities for broadband PPDR.[10] Among these are GIS services, automatic location, a command “white board”, vehicle-mounted video, aerial video, and helmet cameras.

In sum, experts and stakeholders in Europe and around the world see a crucial and growing need for broadband for mission critical PPDR traffic going forward.

Mission critical traffic is likely to be subject to stringent requirements in regard to *security*, *coverage*, *reliability*, and *robustness* (i.e. the ability to continue to operate,

10 NPSTC, Public Safety Communications Assessment 2012-2022: Technology, Operations, & Spectrum Roadmap, Final Report, 5 June 2012.

perhaps with modest loss of performance, even in the face of substantial disruption to the network). Commercial networks typically do not fulfil these requirements today.

- **Security:** PPDR networks will tend to have requirements that security experts would refer to as authorisation, authentication, integrity, and privacy. It must be possible to quickly and automatically establish that a network user is who he claims to be, and that he has authority to make the use of the network that he wishes to make. The transmitted data must not be vulnerable to modification by third parties (malefactors/hackers). Last but not least, for reasons both of security and of consumer privacy, it must not be possible for third parties to "snoop" on the transmissions.

- **Coverage**: Commercial mobile networks often concentrate coverage on densely populated areas and/or major transportation corridors. PPDR needs also tend to be greater where population is greater, but coverage needs can be wider and less predictable than in commercial networks.

- **Reliability and robustness:** No network is immune to all threats; however, the PPDR network needs to be functional if at all possible even in the face of a substantial natural or man-made disaster. This implies a risk assessment profile that is substantially different from that of commercial mobile networks. There are implications not only for reliability and redundancy of equipment, and for stocking of spare parts, but also for availability of service personnel even in times of crisis. A particular concern with commercial services is that they tend to be over-loaded during disasters to the point where usability by consumers, to say nothing of PPDR forces, becomes difficult if not impossible.

2.2 Assessing bandwidth requirements and spectrum requirements of PPDR applications

In assessing PPDR application needs for bandwidth and for spectrum, it is helpful to use a taxonomy employed in FM 49's work in ECC Report 199:[11]

- day-to-day operations (category "PP1");

- large emergency and/or public events (category "PP2"); and

- disasters (category "DR").

Interestingly, PPDR is one of the few applications where *upstream broadband bandwidth tends to be greater and even more crucial than downstream.* Commanders at headquarters want to know what is happening in the field. It is somewhat less

11 The taxonomy has its roots in the IABG and WIK studies for the German government in 2010, op. cit.

essential for field personnel to see the "talking heads" of their respective commanders.[12]

Previous studies, including ECC Report 199, acknowledge a difference between mission-critical and non-mission-critical PPDR activities. The use of commercial networks for non-mission-critical services might be less problematic than the use of commercial networks for mission-critical PPDR activities involving the safety of property and human life.[13]

Taking all of this into account, and based on a variety of use cases reflecting daily operation (PP1), major events such as the royal wedding in the UK (PP2), and the unplanned/disaster London riots (PP3), ECC Report 199 concludes that *a minimum of 2 x 10 MHz spectrum is required* for mobile broadband PPDR data services. These spectrum requirements for broadband PPDR do not include voice communication, Direct Mode Operation (DMO), Air-Ground-Air (AGA), or ad hoc networks.

As the report summarises, "… with proper network planning a spectrum amount in the range of 10 MHz for uplink and another 10 MHz for downlink is sufficient to cover the PP1 cases [i.e. the public protection cases, but not necessarily all major events or disasters] addressed in this report."

"It is considered that 10 MHz of spectrum for the uplink and another 10 MHz for the downlink provide enough capacity to meet the core requirements of the PP2 scenarios [i.e. the royal wedding use case] presented in the study." The report goes on to note the possible need for additional resources to be deployed: "The estimates for PP2 scenarios do not take into account the additional capacity that could be set up in advance of a planned event (such as the specific scenario used in this estimate). It is difficult to quantify which portion of traffic could be diverted towards the additional temporary capacity, but one can expect that in some cases part of the bandwidth estimated in the tables above may be substituted by temporary capacity."

PPDR spectrum requirements are higher in some European countries. According to the Fritsch et al. study (2010) for the German Ministry of the Interior, and the Marcus et al. study (2010) for the German Ministry of Economics,[14] an additional 15 MHz of spectrum are required in Germany just to meet AGA requirements, albeit not necessarily in the

12 This was first observed in Fritsch et al. (2010), and has been carried forward in ECC Report 199, which notes that "uplink communications require more bandwidth than downlink communications."

13 Cf. ECC Report 199: "Both BB PPDR WAN and temporary additional capacity are supposed to provide radiocommunications to PPDR users in mission critical as well as in non-mission critical situations. Mission-critical communication requirements are assumed to be more stringent than those in non-mission critical situations."

14 Fritsche, Wolfgang/Mayer, Karl (20 May 2010): Studie zum mittel und langfristigen Kapazitätsbedarf der BOS in der drahtlosen Kommunikation, IABG; J Scott Marcus, John Burns et al. (2010): "PPDR Spectrum Harmonisation in Germany, Europe and Globally".

bands below 1 GHz. Since the Marcus et al. (2010) study also identified a need for 10 MHz downstream and 15 MHz upstream to satisfy PP1 requirements, it called for an aggregate of 40 MHz of high quality spectrum to meet German PPDR needs.

For comparison, the US NPSTC found that major incidents such as a hurricane, toxic gas leak, wildfire, or chemical plant explosion could require from 13.5 to 27.7 MHz of spectrum.[15] A number of these incidents would have exceeded the uplink capacity of a 2 x 10 MHz allocation.

We considered the need to supplement sub-1 GHz spectrum with additional ad hoc spectrum in our 2010 study for the German Ministry of Economics (BMWi).[16] If supplemental capacity is required, it is largely limited to the vicinity of the event (i.e. for localised communication), and there is typically time to plan ahead for those instances where additional wide area capacity is needed (for sporting events such as for instance the Olympics, a command post can be deployed in advance, with back-haul to headquarters over the fixed telecoms network). Many of the localised communication needs can be met using short-range wireless technologies like Wi-Fi. For a disaster, a truck roll is probably necessary and appropriate, with backhaul either over the fixed network if available or else over microwave with directional antennas (or possibly satellite for more remote locations). Communications at the site might entail either Wi-Fi in the 5 GHz band,[17] or LTE mobile traffic in the 2.6 GHz or 3.4 to 3.8 GHz bands, or some mix of the two.

2.3 The need for harmonised PPDR technology

For the PPDR community in Europe, there is a clear and obvious advantage in the use wherever possible of *Commercial Off The Shelf (COTS)* equipment, with such PPDR functionality as may be needed (authentication, authorisation, privacy and integrity in the cybersecurity sense, high availability, and group call for voice) layered on top.

Our 2010 study for the German Ministry of Economics (BMWi) did not specifically assume the use of LTE technology, but our estimates used modelling assumptions that are consistent with LTE. It has since become fairly clear that LTE and its successors will be the technology of choice for PPDR broadband. First, there is a clear movement among network operators toward LTE and successors, and away from competing technologies such as WiMAX. Second, the clear preference of the US FCC, NTIA and public safety community for LTE likely creates critical mass on the manufacturing side.

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15 NPSTC, Public Safety Communications Assessment 2012-2022: Technology, Operations, & Spectrum Roadmap, Final Report, 5 June 2012.

16 J Scott Marcus, John Burns et al. (2010): “PPDR Spectrum Harmonisation in Germany, Europe and Globally”.

17 Sharing between PPDR and Wi-Fi in the 5150-5250 MHz band is already envisioned in ITU frequency planning, where PPDR usage is permitted at higher power than Wi-Fi.

It is important to note that the use of LTE technology represents only a starting point for PPDR broadband interoperability. To achieve full PPDR interoperability will also require some degree of standardisation and/or commonality in the applications that are deployed, and in any security arrangements layered on top of the basic communications infrastructure.

3 Cost and benefits of a harmonised spectrum allocation for broadband PPDR

In Marcus and Burns et al. (2010), we found that even small improvements in the effectiveness of PPDR response could have a large socio-economic payback. Europe experiences somewhat fewer natural disasters than some other regions of the world, but we experience enough. The average loss per year from 2002 through 2011 was some $11.7 billion (in 2012 US dollars), or about €9 billion per year (see Table 3). Losses of $24.6 billion US in 2012 were twice as great as the average for the prior ten years. The number of disaster victims[18] in Europe is far less than in other regions such as Asia and Africa, but at an average of some 660,000 per year it still represents a substantial loss in economic terms and a greater loss in human terms (see Table 4).

Table 3: Average annual damages ($US billion) caused by reported natural disasters (2002-2012)

Damages (2011 US$ bn)	Africa	Americas	Asia	Europe	Oceania	Global
Climatological 2012	0.00	22.46	0.02	4.15	0.00	**26.63**
Avg. 2002-11	0.04	2.79	3.50	2.76	0.39	**102.57**
Geophysical 2012	0.00	0.68	2.14	15.80	0.00	**18.62**
Avg. 2002-11	0.57	4.08	36.73	0.53	2.47	**44.36**
Hydrological 2012	0.83	0.58	19.25	4.24	0.70	**25.61**
Avg. 2002-11	0.31	3.95	13.51	4.73	1.16	**23.66**
Meteorological 2012	0.10	79.67	6.56	0.01	0.15	**86.48**
Avg. 2002-11	0.07	39.14	8.19	3.64	0.77	**51.81**
Total 2011	**0.93**	**103.38**	**27.97**	**24.20**	**0.85**	**157.34**
Avg. 2002-11	***0.99***	***49.96***	***61.93***	***11.66***	***4.78***	***129.33***

Source: CRED, Annual Disaster Statistical Review 2012

Table 4: Average annual victims caused by reported natural disasters (2002-2012)

No. of victims (millions)	Africa	Americas	Asia	Europe	Oceania	Global
Climatological 2012	28.01	1.82	6.37	0.45	0.00	***35.21***
Avg. 2002-11	23.86	1.36	76.80	0.27	0.00	***102.57***
Geophysical 2012	0.00	1.41	1.48	0.03	0.00	***2.91***
Avg. 2002-11	0.08	0.83	7.13	0.01	0.07	***8.12***
Hydrological 2012	9.34	1.54	53.52	0.10	0.24	***64.74***
Avg. 2002-11	2.08	4.26	111.05	0.28	0.06	***117.71***
Meteorological 2012	0.47	0.80	18.93	0.00	0.02	***20.22***
Avg. 2002-11	0.37	2.19	37.05	0.11	0.04	***39.75***
Total 2012	**37.82**	**5.57**	**80.29**	**0.58**	**0.26**	***124.52***
Avg. 2002-11	***26.38***	***8.64***	***232.03***	***0.66***	***0.17***	***267.88***

Source: CRED, Annual Disaster Statistical Review 2012

18 In the CRED publications and databases, a *victim* is defined as someone who is killed or affected.

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 degree to which broadband can improve PPDR effectiveness is not yet known with certainty; however, if PPDR effectiveness could be improved and disaster losses reduced by just 5% by means of broadband PPDR communications (which seems to be an extremely conservative estimate), that alone would produce about € 450 million per year[19] in savings for Europe, not counting the value of lives saved in a disaster, nor the value of crimes deterred or of better fire protection and emergency medical services. We return to this point later in this chapter, as we compare societal costs to benefits of allocating spectrum exclusively to enable broadband PPDR.

We are all aware of the risk of disasters that span multiple European Member States, but it is perhaps worth noting that examples are by no means rare. Earlier this year (2013), major flooding is affecting not only large portions of Germany, but also western regions of the Czech Republic (Bohemia), Austria, Switzerland, Slovakia, Belarus, Poland, and Hungary. Dozens of fatalities have been attributed to the flooding, and it is clear that the flooding has caused substantial property damage.

Figure 1: Flooding in Chemnitz, 10 June 2013

Source: Wikimedia Commons[20]

19 This represents 5% of the average annual losses of some € 9 billion. In 2012 (a year of higher than average disaster losses), the savings would have been more than twice as great.

20 Wikimedia Commons, by “gravitat-OFF from Germany”, 2 June 2013, Hochwasser an der Bierbrücke.

In Marcus and Burns (2011),[21] we also noted that the cost of each violent crime averted through better response capability is far higher than might be expected. A US study (de Lisi et al. (2010)) found that the overall cost of a violent crime – considering not only the negative impact on the victim, but also impacts to the perpetrator, costs to the criminal justice system, and costs imposed on all others who take measures (e.g. increased insurance) to mitigate the risk of becoming victims are enormous. The combined societal socio-economic cost of a single murder was found to be in excess of $17 million (about € 13.5 million).[22] One can truly say that an ounce of prevention is worth a pound of cure.

Indeed, even though murder is a relatively rare event in Europe compared with some other parts of the world, the aggregate costs are significant. Combining UNODC crime statistics[23] with the estimated costs in de Lisi et al. (2010), the cost per Member State is significant (ignoring for the moment the far greater cost in human suffering). We caution that cross country comparisons of crime statistics is notoriously difficult, not only because of differences in reporting but also because some crimes are under-reported. Having said that, the costs in Table 5 are per million inhabitants, and thus would need to be multiplied by the number of millions of inhabitants (e.g. some 80 million for Germany) to compute the total cost to a Member State.

Table 5: Estimated societal costs of homicides

	Murders per year per 100K	Annual cost per million inhabitants
France	1.1	€ 148,242,188
Germany	0.9	€ 121,289,063
Italy	1.0	€ 134,765,625
Spain	0.8	€ 107,812,500
UK	1.2	€ 161,718,750
Poland	1.1	€ 148,242,188

Sources: Homicides from UNODC, cost per homicide from de Lisi et al. (2010), WIK calculations

Against any savings or benefits, one must weigh the costs of allocating spectrum to PPDR usage. For the moment, we consider exclusive allocations, leaving the exploration of shared usage to Chapter 6. In our 2010 study for the German government,[24] the largest costs by far proved to be (1) the opportunity cost associated with not using the spectrum allocated to PPDR to some other use such as mobile

21 J Scott Marcus, John Burns et al. (2010): "PPDR Spectrum Harmonisation in Germany, Europe and Globally".
22 Matt DeLisi et al. (2010), "Murder by the Numbers", Iowa State University.
23 UNODC (2012), "UNODC Homicide Chart by Country", at http://www.unodc.org/documents/data-and-analysis/statistics/crime/Homicide_statistics2012.xls.
24 J Scott Marcus, John Burns et al. (2010): "PPDR Spectrum Harmonisation in Germany, Europe and Globally".

services, and (2) the cost of re-farming the spectrum away from the incumbent use. For spectrum under 1 GHz, we found that the opportunity cost substantially exceeded typical re-farming costs, and that other costs were small by comparison to the opportunity cost.[25] In this case, since the 700 MHz band will presumably be reassigned one way or another, the re-farming costs can be viewed as sunk costs that are irrelevant to the analysis.

The *opportunity cost* is the value that the spectrum would have had if it had been allocated to some high value application other than PPDR (and thus the value that is lost by allocating the spectrum exclusively to PPDR, which must subsequently be compared to the gains to PPDR services). For spectrum under 1 GHz, mobile voice and data services are widely recognised as being high value, and the fact that no buyers seem to be visible who would be willing to pay more than Mobile Network Operators (MNOs) at auctions of sub-1 GHz spectrum supports this view. To an economist, a good measure of value is the price that a knowledgeable buyer is willing to pay. For these reasons, spectrum auction prices paid by MNOs for comparable bands represent a good estimate of the opportunity cost associated with an exclusive allocation to PPDR.

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

Given that Member State auctions of digital dividend spectrum in the 800 MHz band are currently ongoing, there is a good base of recent experience with a spectrum band with similar characteristics in terms of coverage, building penetration, and other relevant physical properties.[26] In a recent article, Analysys Mason estimated the market value of 800 MHz spectrum at € 0.51 per MHz/POP, i.e. € 0.51 per MHz for each person potentially covered in the geographic area.[27]

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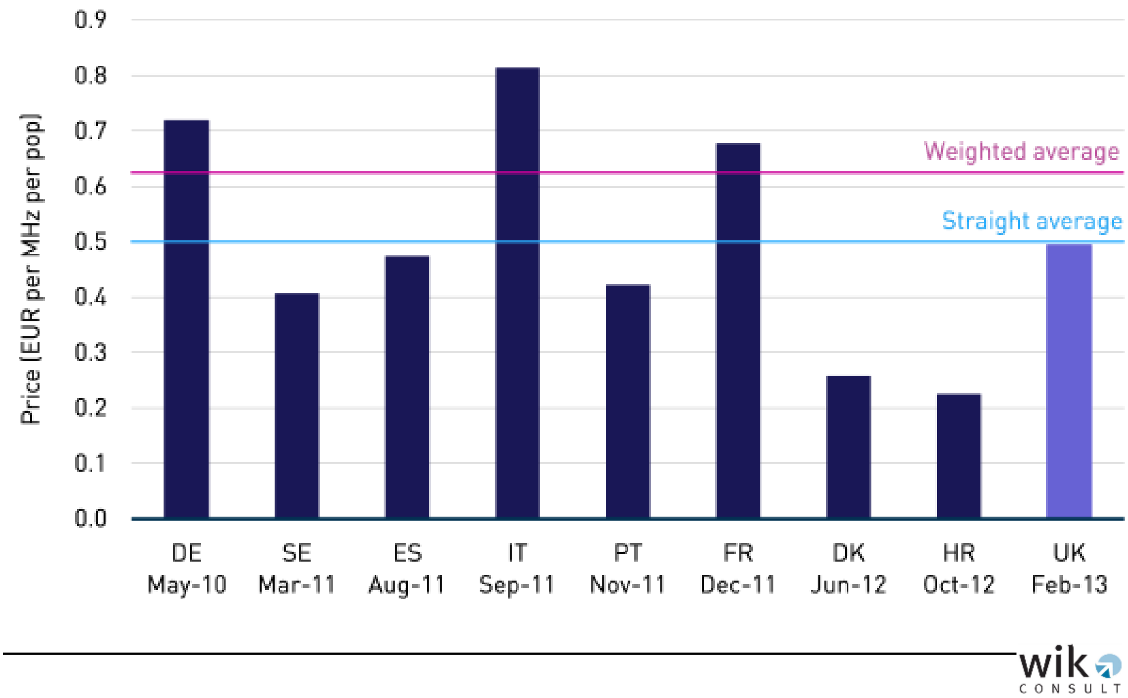
25 Marcus and Burns et al. (2010), op. cit.

26 The 700 MHz has somewhat greater coverage than 800 MHz, but for purposes of this rough analysis we will assume the value to be similar to that of 800 MHz.

27 Phillip Bates (2013), 4G spectrum auction in the UK: were the prices paid low or merely average?, Analysys Mason, at http://www.analysysmason.com/About-Us/News/Insight/4G-spectrum-UK-Feb2013/#.UkO98aJBvct. They considered the simple average to be more appropriate than the weighted average (which would have been about 20% higher).

Figure 2: Prices paid in 800 MHz auctions



Source: Analysys Mason (2013)

Key: DE = Germany, DK = Denmark, ES = Spain, FR = France,
HR = Croatia, IT = Italy, PT = Portugal, SE = Sweden, UK = UK.

These results are broadly consistent with those of a 2012 study conducted by Dotecon and Aetha on behalf of Ofcom, the UK Spectrum Management Authority.[28]

If we take the population of the European Union (EU-28) to be 512.2 million, this implies a Willingness to Pay (WTP) on the part of alternative high-value users of € 5.2 billion for 20 MHz of spectrum in the 700 – 800 MHz range.

In comparing this cost to the benefits of PPDR broadband use, it is necessary to annualise the cost (since this price is for a licence of many years). Spectrum licences acquired at auction could be said to have a typical duration of 15 to 25 years.[29] Assuming a 20 year average licence, and spreading the cost in the simplest straight line way over the 20 years, yields an annual cost of some € 260 million in constant 2012 euro.[30]

28 DotEcon and Aetha (2012), Spectrum value of 800 MHz, 1800 MHz and 2.6 GHz: A Report for Ofcom, July 2012.

29 Cf. Ibid., Table 10.

30 In the interest of simplicity and since the results are clear enough, we ignore in this quick analysis the cost of money, inflation, and numerous other complicating factors.

This is unambiguously less cost than the annual benefits (about € 450 million per year, as noted earlier in this section) in savings for Europe that even a modest 5% improvement in the cost of disasters due to improved effectiveness of disaster relief would generate, without even considering the value of lives saved in a disaster, nor the value of crimes deterred or of better fire protection and emergency medical services.

This European analysis is broadly consistent with a just-completed assessment for the Asia-Pacific region,[31] which found: "On a social cost-benefit basis the benefits of assigning broadband spectrum to dedicated PPDR services on an exclusive basis far outweigh the costs as measured by opportunity cost. There is justification on a cost-benefit basis for allocating the spectrum that is considered sufficient for national needs."[32]

31 Australia, China, Indonesia, Malaysia, New Zealand, Singapore, South Korea and Thailand.

32 John Ure (2013), "Public Protection and Disaster Relief (PPDR) Services and Broadband in Asia and the Pacific: A Study of Value and Opportunity Cost in the Assignment of Radio Spectrum".

4 Available options below 1 GHz

As previously noted, radio spectrum frequency bands below 1 GHz offer two key advantages for PPDR broadband.

- First, full coverage of the national territory is far more cost-effective in these frequencies.
- Second, spectrum below 1 GHz is vastly superior for building penetration (particularly in dense urban areas with a high proportion of concrete and steel structures), which is often required for PPDR.

It has been well understood for many years that there are only two potential options for harmonised spectrum below 1 GHz that are realistically available in Europe: (1) somewhere in the NATO bands (for those countries where NATO operates); or (2) spectrum that will be freed by over-the-air broadcast as a result of the Digital Dividend.[33] *Nowhere else under 1 GHz could spectrum be found that could be harmonised, either at European or at global level.*

Realistically, the NATO bands are not a very attractive or practical option. First, NATO is subject to its own increased spectrum demands for many of the same reasons as PPDR (new bandwidth-hungry applications; video from the field to headquarters; helmet cameras; and unmanned vehicles on land, sea and air). Second, NATO is strongly disinclined to give up the spectrum, and it would be nearly impossible for any national government or international body to require them to do so. Third, those bands are not adjacent to existing LTE bands, which would probably have implications for antenna design and perhaps for other aspects of equipment design.

This last point is worth dwelling on. At this point, it is fairly clear that LTE will be the preferred technology choice globally for PPDR broadband. Antenna design greatly benefits if the spread of the frequencies from the mid-point is not more than about 10%.[34] This argues that it would be advantageous for PPDR sub-1 GHz spectrum to be adjacent to or encapsulated within designated LTE bands.

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33 There has also been some interest in the 410-470 MHz range, but it would be difficult if not impossible to achieve harmonised conditions (to say nothing of a harmonised band) in this range.

34 This follows from the analysis of the bandwidth and performance limitations of small antennas that was first developed many years ago by Chu and subsequently further refined by Harrington and MacLean. Chu and Harrington developed a specific relationship that defines the maximum available bandwidth for a small two-pole antenna. MacLean determined that the theoretical minimum Q factor for a small antenna (i.e. where the antenna size is smaller than a wavelength at the operational frequency). See Chu, LJ, "Physical Limitations on Omni-Directional Antennas," *Journal of Applied Physics,* Volume 19, pg 1163, December 1948; Harrington, RF, "Effect of Antenna Size on Gain, Bandwidth, and Efficiency," *Journal of Research of the National Bureau of Standards*, Volume 64-D, pg 1, January/February 1960; and MacLean, J.S.: 'A re-examination of the fundamental limits on the radiation Q of electrically small antennas', *IEEE Trans Antennas Propagat.*, 1996, 44, pp. 672–676.

There are analogous advantages for the design of end user equipment. As Paul Jacobs, CEO of Qualcomm, recently explained: "[T]here are already over 30 LTE frequency bands around the world ... Having so many different frequency bands creates difficulties for the development and design of LTE devices. In particular, the front end of the phone – the components that manufacturers place in between the antenna and the digital modem – requires discrete band-specific components for each and every operational frequency in a phone. In today's sleek smartphone designs, an OEM simply runs out of printed circuit board area before it can fit in all the front end components and may need up to 10 or more versions of each LTE handset design in order to sell a particular phone model around the world."[35]

Much of our analysis in this study is in the context of a harmonised spectrum band or pair of bands and a dedicated PPDR network at the national / Member State level; however, it is already clear that some Member States will prefer other arrangements, and it is also uncertain that a harmonised band within the European Union, to say nothing of the full range of the CEPT, is achievable.

With that said, the considerations already noted regarding antenna design and manufacturing economies of scale apply with even greater force:

- In countries where there is a desire to use commercial LTE for non-mission-critical services, together with a dedicated network using LTE technology for mission-critical PPDR applications;
- In countries where there is a desire to use commercial LTE for lower risk areas, together with a dedicated network using LTE technology for higher risk areas; or
- In countries where there might be a desire to make PPDR spectrum available for commercial LTE use (see Chapter 6), since handsets for commercial consumer use would have to support the PPDR band in question.

In previous work, our colleagues suggested using spectrum from the first Digital Dividend;[36] however, there was at the time no general consensus that more spectrum was needed for broadband PPDR. That ship has sailed.

With a second Digital Dividend coming as a result of the WRC 2012 decision, there exists another opportunity to drive a political consensus or compromise that would require or at least permit the use of 700 MHz spectrum for broadband PPDR. An allocation somewhere between 694 and 790 MHz seems to us to be the most promising range for the establishment of harmonised conditions for spectrum below 1 GHz for PPDR broadband today. If a harmonised band cannot be achieved, then a tuning range should be considered. Countries wishing to implement broadband PPDR according to national needs would then be able to freely choose the required LTE spectrum blocks from within that range without sacrificing the seamless roaming capabilities as called for

35 Frédéric Pujol (2013), Interview with Paul E. JACOBS, Qualcomm's Chairman & CEO *Communications & Strategies* No.90, second quarter 2013.

36 Kenneth Carter and Val Jervis (2007), "Safety First".

by the Commission in the RSPP. The LTE technology would then allow PPDR terminals to find and connect with the available PPDR network without the need for a single strictly harmonised band across the EU, or in all 48 CEPT Member countries.

5 Why auctions should not be used to assign PPDR spectrum

Perhaps the most important innovation in spectrum management in the past twenty years has been the widespread use of market mechanisms, and especially of auctions, to make spectrum assignments. From a spectrum management perspective, the purpose of an auction is to ensure that spectrum is assigned to the user who values it most.[37] It is assumed, other things being equal, that the highest bidder will also tend to be the party with greatest ability and motivation to put the spectrum to use in a way that benefits society.

When determining spectrum assignments among commercial entities, the use of auctions seems to work well (assuming that the auction itself is well designed), and the use of auctions is widely felt to be superior to the purely administrative assignment that was often done in the past. There are many instances, however, where auctions are not used to assign spectrum. Auctions have hardly ever been used for PPDR spectrum, and in our view with good reason.[38]

An auction cannot properly reflect the value of PPDR spectrum due to *fragmentation and transaction costs within the PPDR community*. When commercial Mobile Network Operators (MNOs) participate in a spectrum auction, they are typically looking to deploy service over the full national territory. In other words, their territory is aligned with that of the auction. By contrast, PPDR providers tend to be highly fragmented, both geographically across the national territory, and functionally (e.g. police, fire, emergency medical, and more). The economic transaction costs associated with aggregating their demand are usually prohibitive. As a result, they cannot bid what the spectrum is really worth to them.

Spectrum auctions achieve good results where the rights associated with the licence are clear, and where the spectrum will be put to effective commercial use. The business case for the service in question provides a basis on which to estimate the value of the spectrum that can be used to provide the service. Conversely, for a service that is not commercially offered, such as PPDR, there is no inherent way to know what value should be assigned to the spectrum at auction. Governments would need to assess the value of the property and human life that they seek to protect, and (especially in the case of disasters) the risks to which they are subject. This is not easy! In the end, it is unlikely that they would place the right bids.

Governments routinely acquire goods and services to meet societal needs. They buy battleships and paper clips, police cars and ambulances. Some might argue that governments should purchase PPDR broadband spectrum at auction, just as does any commercial party who needs spectrum. In this case, however, an auction would not generate the societally optimal result.

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37 Ronald Coase (1959), The Federal Communications Commission.
38 The notable exception is the US FCC’s failed “D Block” auction.

As noted previously in this study, and as substantiated by other studies throughout the globe, the societal benefits that would accrue to the allocation of a minimum of 2 x 10 MHz of broadband spectrum below 1 GHz to PPDR broadband exceed the value that the spectrum could be expected to bring in an auction (which is a crucial measure of the opportunity cost of choosing not to allocate the same spectrum for commercial mobile use); however, it is exceedingly unlikely that governments would recognise the need to bid enough themselves if there were a way to do so, and even less likely that they could individually coordinate their actions so as to achieve a harmonised band or tuning range across all of Europe.

For analogous reasons, secondary market mechanisms such as spectrum trading or, in this case, possible use of *Administrative Incentive Pricing (AIP)* provide only a limited indication of the true value of the spectrum. As countries that implement AIP well know, AIP can be useful in making proper trade-offs between spectrum cost and equipment cost when a new system is procured; however, AIP is of little value for subsequent corrections, because it is generally impractical either (1) to allow the agency in question to apply economic savings to, for example, hiring more troops or buying more tanks, or (2) to reflect such revenues in the compensation of the public servants who make the decisions to sell or lease otherwise underutilised public spectrum. Again, requiring PPDR organisation to acquire spectrum through commercial arrangements is unlikely to be efficient, and very unlikely to produce the harmonised conditions that are called for here.

For all of these reasons, PPDR spectrum has tended historically to be provided under administrative assignment, and rightly so in our view.

6 Shared use of spectrum for PPDR and commercial LTE

While we believe that a case has been made for a minimum of 10 + 10 MHz of broadband spectrum to be allocated to public safety for dedicated use throughout the region,[39] we also believe that consideration should be given to broadband PPDR spectrum allocation policies which recognise possible use of primary/secondary allocation and/or by sharing arrangements to address the unique circumstances amongst different countries and how PPDR broadband spectrum should be allocated and used.

- Most countries are likely to wish to have dedicated networks that are entirely capable of handling requirements for PPDR broadband applications. This enables reliance on dedicated PPDR networks having greater resilience, reliability, coverage, and security than those of commercial networks, as well as enabling local control and dynamic prioritisation.[40]

- Some countries may consider allocating spectrum for shared use between the PPDR and commercial usage. If this is the only spectrum available for PPDR broadband within a country, it would be critical for PPDR to have primary use of a sufficient quantity of the spectrum. As shared access technology evolves, it could be possible, however, for PPDR to selectively relinquish access to some PPDR spectrum for commercial use during periods of low stress (using for instance the *Authorised Shared Access [ASA]* model).[41]

- Some countries may wish to place full reliance on the use of commercial mobile networks, including broadband. This may reflect a desire for auctions revenues, scepticism regarding PPDR broadband requirements, together with a view that commercial networks are sufficient to meet public safety requirements.

Most PPDR provider organisations have a strong preference for a dedicated network (e.g. current use of their own TETRA or TETRAPOL networks) for their mission critical service in combination with a commercial mobile service for non-essential communication.[42] Reasons for this preference include:

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39 As noted in Section 2.2, the estimate does not include voice communication, Direct Mode Operation (DMO), Air-Ground-Air (AGA), or ad hoc networks; moreover, the needs of high demand countries such as Germany may be greater.

40 See also NPSTC, Public Safety Communications Assessment 2012-2022: Technology, Operations, & Spectrum Roadmap, Final Report, 5 June 2012.

41 See for instance Ingenious Consulting Network (2010). “Authorized Shared Access (ASA): An evolutionary spectrum authorization scheme for sustainable economic growth and consumer benefit”; and Antonio Nicita and Maria Alessandra Rossi (2013), “Spectrum Crunch vs. Spectrum Sharing: Exploring the ‘Authorised Shared Access’ Model”, *Communications & Strategies* 90, 2nd quarter 2013 (forthcoming).

42 See for instance TCCA (2013), Future Broadband Spectrum needs for PPDR: Communiqué from Roundtable discussion, 23 May 2013. “The PPDR user and operator representatives [at the London meeting] supported the view that it is essential for governments’ organisations to control enough dedicated and harmonised spectrum in order for their organisations to deliver service to society. The robustness, availability and security

- Dedicated PPDR networks can be designed for greater *robustness* than commercial networks. Robustness is related to reliability, but it is not exactly the same thing. Robustness also entails the ability to continue to operate in the face of stress (such as flooding, severe weather, earthquake, power outage, or civil disorder). A commercial mobile network is designed to remain operational a high proportion of the time, but typically has limited ability to operate in the face of flooding or loss of power (typically batteries are provided at cell sites, for instance, but no power generators). Times of stress are precisely the times when the continued and reliable operation of a PPDR network is most needed.

- Commercial networks tend to be subject to heavy overload during a disaster or crisis. These tend to be precisely the times when it is most critical for PPDR personnel to have reliable communications. PPDR professionals are deeply concerned about the high likelihood of overload, and lack of prioritisation, in commercial networks.[43]

- Reliable operation at times of stress requires conscious planning at all levels, including personnel planning. Network operations personnel need to be deployed where they are needed, rather than remaining with their families (where they would typically prefer to be at a time of stress). The chain of command and a wide range of operational issues need to be carefully planned. It would be exceedingly difficult to manage such arrangements solely as a matter of contract with a conventional mobile network operator.

Food for thought 3: Mobile networks fail during a power outage[44]

> The regular public telephone network generally kept working after the power went out in parts of six states yesterday afternoon, but the cellular systems in affected areas were often unable to cope.
>
> Wireless network operators said their networks were unable to handle the heavy traffic as large numbers of people simultaneously tried to reach friends, family and business associates. But the lack of electricity or the failure of backup power systems at cellular transmitter stations and traffic switching centers were also partly to blame. While the transmitter stations typically have battery backup power, the batteries may not last more than a few hours.

requirements of Mission Critical Operations cannot be ensured relying on commercial spectrum."

43 These concerns are discussed in NPSTC, Public Safety Communications Assessment 2012-2022: Technology, Operations, & Spectrum Roadmap, Final Report, 5 June 2012. "Responders repeatedly expressed concern over the lack of data priority on commercial systems, as well as inconsistent coverage for public safety needs."

44 Matt Richtel and Simon Romero (2003), The Blackout ff 2003: Communicatoins; When Wireless Phones Failed Because of Heavy Use, Callers Turned to Land Lines, New York Times, 15 August 2003.

The land-line telephone network, which is built with backup power through the system and sends a small electrical current to each phone, continued operating, although spikes in calling volume sometimes caused callers to encounter fast busy signals. Verizon, the main telephone provider in the Northeast, said that in the first hour after the power failure, call volume was 300 percent above normal levels in the metropolitan New York City area.

With that said, one could envision multiple models for allocating and assigning spectrum so as to permit varying degrees of flexibility between PPDR use and commercial use by an MNO. Possible scenarios include:

- **Inflexible:** Fixed (dedicated) assignment of bands (nominally 2 x 10 MHz) to broadband PPDR. ECC Report 199 concludes that this is likely to be sufficient to meet PPDR day to day (PP1) needs in most countries, and to provide basic support for special events (PP2), but provides no ability to use more spectrum at times of stress (e.g. disasters (DR)), nor does it permit unused spectrum to be put to use at times of low activity.

- **Flexible:** Fixed assignment of bands (nominally at least 2 x 10 MHz) to broadband PPDR, but the PPDR operator has the option to sub-licence rights of use to any portion of the bands that is unused (based on time or geography) pursuant to an ASA arrangement. This may or may not be combined with sub-contracting operation of the PPDR network to the same entity, subject to suitable contractual conditions. This type of arrangement permits unused PPDR spectrum to be put to use by commercial operators at times or locations of low PPDR activity; however, it provides no ability for commercial operators to use the spectrum when and where needed by PPDR.

- **Highly flexible:** Fixed assignment of somewhat larger bands (such as 2 x 20 MHz) to broadband PPDR. The PPDR operator sub-licences rights of use for a substantial portion of the bands (e.g. 2 x 10 MHz) pursuant to an ASA arrangement, but with rights to reclaim them only under limited circumstances (such as a declared emergency). The PPDR operator would retain priority use of the bands under normal circumstances, but would again sub-licence rights of use to any portion of the bands that is momentarily or geographically unused pursuant to an ASA arrangement. Again, this might be combined with sub-contracting operation of the PPDR network to the same entity, subject to suitable contractual conditions. These arrangements permit unused spectrum to be put to use by commercial entities at times and locations of low PPDR activity, in addition to providing commercial entities the ability to use substantially more spectrum at times of stress.

- **Inflexible and inadequate:** No fixed assignment of bands to broadband PPDR. This would leave broadband PPDR fully dependent on commercial MNOs, or existing TETRA/TETRAPOL networks that are insufficient to meet projected needs for broadband PPDR. A significant risk is that even if such arrangements might superficially appear adequate on a day to day basis, they would likely collapse under stress.

ASA arrangements could in principle be quite flexible, allowing use to be managed by geographic location, by time of day, or in this case depending on whether some natural or man-made disaster was in progress. In practice, the ASA arrangements that we propose here would be quite complex; however, we are of the view that they are manageable.

The reader will naturally wonder how this approach compares to efforts in the United States to provide a spectrum band preemptible by PPDR as part of its "D Block" auction. The US FCC attempted to "… award a nationwide 10 megahertz 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."[45]

Unfortunately, this approach failed in the US.[46] Commercial operators did not have sufficient interest in the preemptible spectrum. Bids failed to reach the FCC's reserve price so the license went unsold at auction.[47]

We believe that the auction in the U.S. failed for two reasons, both of which could potentially be avoided in future implementation of shared spectrum use between PPDR and a commercial MNO:

- First, the detailed arrangements for the band were extraordinarily complex, and consequently introduced enormous uncertainties for bidders. These uncertainties presumably reduced the effective commercial value of the band.

- Second, the commercial value of a band that could be pre-empted by PPDR in an emergency was probably less than the FCC assumed. We believe that the PPDR user community will tend to be in a better position to manage sharing arrangements than the federal Spectrum Management Authority envisioned by the FCC. A national authority representing the PPDR user community could for

45 US FCC, at http://www.fcc.gov/pshs/public-safety-spectrum/700-MHz/safetyband.html.

46 The US FCC continues to work toward establishing, in portions of the 700 MHz band, a nationwide interoperable wireless broadband communications network for the benefit of public safety users. See FCC (2011), 'Implementing a Nationwide, Broadband, Interoperable Public Safety Network in the 700 MHz Band', FCC 11-6, Jan 25, 2011.

47 Subsequently, in 2012, the U.S. Congress recognized the need for additional dedicated spectrum for public safety broadband, and allocated that 10 MHz block to public safety, along with an already existing 10 MHz block.

instance use a competitive procurement that simultaneously (1) determines the operator for the national broadband PPDR network, and (2) provides some compensation back to the network operator (the winning bidder) as "payment in kind" in the form of rights to use the same network, and the same spectrum, when not otherwise required for PPDR usage, thus defraying the cost (or perhaps making the cost negative). The public procurement serves exactly the same function in this case as a spectrum auction, ensuring that the spectrum will tend to be provided to the party that can make best use of it; however, it also serves to take balanced cognizance of providing the PPDR network services at lowest cost to the PPDR user community.[48]

Whether such a sharing arrangement is warranted would have to be evaluated on a case by case basis. It may be that the societal benefits of sharing in this way are too small to justify the complexity and administrative overhead of sharing, either because the amount of spectrum that could potentially be shared is too small, or because the encumbrances would be so great as to make sharing uninteresting for a commercial network operator.

We do not suggest that every country will want to avail itself of such sharing, even where it might be economically warranted, but we present it here in order to show that it is possible. For sharing to be effective, it is important that the technology, administration, and economics of network sharing be thought through carefully.

Further study of these issues is warranted. The European Commission has issued a request for tenders for a study along these lines, which we view as a positive step. We acknowledge that it is unlikely that there will be a fully elaborated and agreed plan as to how to do this in time for the WRC in 2015.

48 This suggestion that it is far more practical for the PPDR user to share with a commercial user, rather than the reverse, is consistent with Ure (2013), op. cit.

7 Key findings and recommendations

Key findings are:

- There are substantial socio-economic benefits in ensuring that PPDR broadband networks can be implemented. As a practical matter, this requires spectrum under 1 GHz.
- ECC Report 199 identifies a need for a minimum of 2 x 10 MHz of spectrum below 1 GHZ for PPDR broadband in Europe, not including requirements for voice communication, Direct Mode Operation (DMO), Air-Ground-Air (AGA), or ad hoc networks. Other studies have recommended high quality spectrum[49] on the order of 40 MHz or even more for PPDR broadband in a high usage country such as Germany.[50]
- The organisations responsible for PPDR are convinced that their needs for mission critical broadband services can only be met by dedicated harmonised spectrum.[51]
- Numerous studies (including this one) have demonstrated that the societal benefits that accrue from the allocation of dedicated broadband spectrum to PPDR in many cases exceed the benefits from using the same spectrum for other uses (as estimated based on expected revenues from auctioning the same spectrum), thereby substantiating requests by PPDR entities and jurisdictions for dedicated public safety spectrum.
- Harmonised conditions in terms of spectrum and technology for broadband PPDR offer obvious and substantial advantages (in terms of scale economies, equipment portability, cross border communications, and enhanced ability for one country to lend assistance to another) over country-specific allocations for PPDR.
- At the present time, only the 700 MHz band range (between 694 and 790 MHz) appears to offer a realistic prospect of a globally or even a regionally

49 Not necessarily all of this spectrum would need to be sub-1 GHz. The spectrum referred to in ECC Report 199, whether 10 + 10 MHz or 10 + 15 MHz, should be below 1 GHz. The AGA spectrum could however be anywhere below roughly 3 GHz,

50 Fritsche, Wolfgang/Mayer, Karl (20 May 2010): Studie zum mittel und langfristigen Kapazitätsbedarf der BOS in der drahtlosen Kommunikation, IABG; and J Scott Marcus, John Burns et al. (2010): “PPDR Spectrum Harmonisation in Germany, Europe and Globally”.

51 See for instance TCCA (2013), Future Broadband Spectrum needs for PPDR: Communiqué from Roundtable discussion, 23 May 2013. “The PPDR user and operator representatives [at the London meeting] supported the view that it is essential for governments’ organisations to control enough dedicated and harmonised spectrum in order for their organisations to deliver service to society. … The meeting could also conclude that there is now unanimous support from the PPDR users and operators to seek such spectrum as part of the World Radio Conference in 2015.”

harmonised European PPDR broadband band or tuning range with the necessary characteristics.

- An auction of sub-1 GHz spectrum (even if governments were able to participate) is unlikely to generate an economically efficient outcome that properly reflects the value of a PPDR allocation to society due to the fragmentation of the PPDR user community, and corresponding challenges in aggregating demand for PPDR broadband spectrum. It is unlikely that governments would bid the correct value, and even less likely that the process would lead to harmonised conditions across Europe.

- Public safety broadband requirements cannot be met by relying exclusively on commercial networks.

- Different countries may have different approaches as to whether PPDR spectrum should be used for dedicated mission-critical networks, for commercial networks that purportedly meet non-mission-critical needs, or for some blend of the two; however, it is technically and administratively feasible to address all of these needs simultaneously (for example by means of judicious use of ASA under carefully crafted conditions). Technical, operational, and economic characteristics of any sharing arrangements would need to be carefully planned (see Chapter 6).

Recommendations that flow from these are:

- European spectrum policymakers, recognising the value of PPDR broadband spectrum, should continue efforts to reach consensus for a harmonised band (or failing this, a tuning range) within the 700 MHz band with an eye to WRC-15.

- CEPT ECC should continue to refine its work on PPDR broadband spectrum requirements.

- Further work is needed on arrangements for sharing spectrum and network capacity for mission critical services, whether in preparation for WRC-15 or beyond. The European Commission has issued a request for tenders for a study along these lines, which we view as a positive step.

- The PPDR community needs to be engaged in identifying its needs, and moving the issue forward.

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