Study on Terrestrial BB-PPDR Spectrum Options

a report from LS Telcom

Consultant Report

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Final Report

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1 Introduction

1.1 General

This document represents the report on a project entitled "Study on Terrestrial Broadband Public Protection and Disaster Relief (BB-PPDR) Spectrum Options" and has been prepared by LS telcom UK Ltd for the Commission for Communications Regulation (ComReg). It represents the results of research and analysis into a variety of network and spectrum options for the provision of BB-PPDR services and sets out the most viable options for Ireland.

1.2 Background

In Ireland, the current public safety network is owned and operated by the incumbent operator, TETRA Ireland which uses the European harmonised spectrum band 380-385 MHz paired with 390-395 MHz. The mission-critical (National Digital Radio Service) network covers 98% overlapping land mass coverage which includes buildings and land areas. It also provides an Air-Ground-Air service for fixed and rotary wing aircraft. The network is interoperable between a range of different agencies including police, fire and ambulance but also Irish coast Guard and Irish Prison Service.

In the last number of years, countries across Europe have started to consider upgrading or replacing their incumbent public safety networks with new BB-PPDR networks. BB-PPDR is a relatively new concept which integrates a broadband capability into a secure, resilient and high availability network. This broadband capability was recognised as the data demand requirements for emergency service end users (i.e. police, fire and ambulance services) increased beyond that which legacy (e.g. Terrestrial Trunked Radio (TETRA)) networks can deliver. For example, the desire to provide high resolution data over the network such as images, maps or sometimes video.

As a result of this technology evolution and potential impact on spectrum usage, ComReg as part of its proposed multi-band spectrum award, appointed LS telcom to study the impact on the different types of network deployment and consider the different spectrum options that arise, notably in the 400 MHz and 700 MHz band ranges.

Specifically, the aim of the project was to gather information and develop an understanding across three key areas including; the existing network deployment options, spectrum options and spectrum requirements needed to support the implementation of a BB-PPDR solution for Ireland.

Given the developments in this area within Europe (particularly the work undertaken in CEPT) and worldwide, the study examines the implications between deploying dedicated networks, access of BB-PPDR applications on commercial networks or a hybrid approach. In addition, ComReg is interested in the available spectrum options examined by the likes of CEPT for BB-PPDR such as what bandwidths could be used and are available in the 410 – 430 MHz and 450 – 470 MHz frequency bands and, of particular interest, is the possibility of using spectrum within the soon to be awarded 700 MHz band for BB-PPDR. The cross-country feasibility analysis is interesting due to the range of possible approaches and decisions being taken within Europe and other markets globally that could help inform ComReg on the possible network deployment and spectrum options.

This work will be used by ComReg in its public consultation for the multi-band spectrum award process which will include a section on BB-PPDR spectrum options to inform stakeholders of the findings from our analysis.

1.3 Structure of this report

This report is split into three main sections and three annexes:

- Section 2 reviews existing material produced by various regional and international bodies concerning the different options which exist for the provision of BB-PPDR services from the perspective of the options for rolling-out a network, and the spectrum used for that network;
- Section 3 examines the situation in a number of European and non-European countries with respect to BB-PPDR network roll-out and spectrum, to garner a view on international trends;
- Section 4 considers the amount of spectrum that would satiate the needs of PPDR users in Ireland and looks at which spectrum options are potentially available that would meet these needs;
- Section 5 describes the conclusions from the findings of the study;
- Appendix A provides a list of the relevant CEPT/ECC reports;
- Appendix B presents technical compatibility issues;
- Appendix C provides a glossary of abbreviations and acronyms found in this report.

2 Review of BB-PPDR deployment and spectrum options

2.1 Introduction

In this section we describe, define and review the key aspects of BB-PPDR network deployment and spectrum options. In particular, we reference existing material from Conference Europeen des Postes et Telecommunications (CEPT) / Electronic Communications Committee (ECC) report and other technical reports from the TETRA and Critical Communications Association (TCCA[1]) and other sources.

Most notably, ECC Report 218[2] and the Radio Spectrum Policy Group (RSPG) Report on Strategic Sectoral Spectrum Needs[3] provide a comprehensive description of all the different potential BB-PPDR deployment options.

2.2 Summary of key aspects of BB-PPDR deployment options

Public Protection and Disaster Relief (PPDR) radio communications' are radio applications used for public safety, security and defence used by national authorities or relevant operators responding to the relevant national needs in regard to public safety and security including in emergency situations.

There are three primary approaches to deploying BB-PPDR networks. In the following sub-sections we discuss in detail these deployment options which include:

- A national dedicated broadband network;
- Support of PPDR applications over commercial cellular networks; and
- Hybrid solutions.

2.2.1 National dedicated broadband network

Historically, PPDR networks in many countries around the world have been based on the deployment of private dedicated networks that are typically procured by Government departments, sometimes with the support of external experts, and which are designed to meet a particular set of safety, resilience and security requirements.

As wide area mobile wireless technology evolved, there has been an increasing requirement for digital features and interoperability. As a consequence, Europe decided to adopt a harmonised approach to PPDR network deployment and spectrum allocation as specified in ERC/DEC(96)01[4]. More specifically, the ERC Decision harmonised the duplex band range 380-385 MHz uplink (UL) paired with 390-395

[1] The TCCA is an industry association for the Tetra and critical communications community http://tcca.info

[2] ECC Report 218 Harmonised conditions and spectrum bands for the implementation of future European Broadband Public Protection and Disaster Relief (BB-PPDR) systems, Oct 2015, https://www.ecodocdb.dk/download/bf3fb2b0-9509/ECCREP218.PDF

[3] Radio Spectrum Policy Group (RSPG), Report on Strategic Sectoral Spectrum Needs, Nov 2013 https://www.cept.org/files/9421/RSPG13-540rev2_RSPG_Report_on_Sectoral_needs.pdf

[4] ERC/DEC/(96)01 ERC Decision of 7 March 1996 on the harmonised frequency band to be designated for the introduction of the Digital Land Mobile System for the Emergency Services

MHz downlink (DL) in Europe for use by TETRA technology. This decision led to the roll out of nationwide dedicated TETRA networks across Europe for the emergency service authorities.

Nationwide dedicated network builds range in scope by orders of magnitude depending on the size of the country, its geography (i.e. predominantly rural, urban or mixed and hilly versus flat terrain) and population of PPDR users, which determine the required number of base station sites. Given the critical nature of the services provided, added security (physical and logical) and resilience requirements are needed which can add to the cost of procurement and roll out.

However, the frequency range (around 380/390 MHz) lends itself to providing wide ranging coverage areas thus minimising excessive infrastructure requirements due to the good wide area propagation it provides. For example, in the UK around 3500 TETRA base stations provide 99% land area coverage[5] (over 242,495 km^2).

In the case of a dedicated mobile broadband PPDR network, the fundamental characteristics are the same as for narrowband such that:

- The network will need its own dedicated (new) spectrum and enough bandwidth to support broadband applications
- The network will need its own dedicated network infrastructure, potentially re-using the existing narrowband infrastructure such as masts to deliver wide area coverage. However, this would be dependent on the frequency band. For example, using the 700 MHz frequency band would deliver an almost equivalent level of coverage compared to 400 MHz, but would need additional infill sites to ensure the cell edge service is maintained across the entire network.
- Capable of supporting a mix of different mobile devices and applications (handheld and vehicle mounted including air to ground)

BB-PPDR is a relatively new concept which integrates a broadband capability into a secure, resilient and high availability network. This broadband capability was recognised as the data demand requirements for emergency service end users increased beyond that which legacy (e.g. TETRA) networks can deliver. For example, the desire to provide high resolution data over the network such as images, maps or sometimes video.

CEPT for example, defines the following model for a dedicated network in ECC Report 199[6]:

> *A network solely designed to fulfil the sovereign PPDR requirements: this can be a GoGo model (Government Owned, Government Operated), but also a service delivered by a third party (CoCo: Company Owned, Company Operated). Another model is GoCo (network owned by Government, but operated by a third party).*

In 2015, the TCCA published a report[7] which describes these models in more detail as shown in Figure 1 below.

[5] The Quixoticity Index 2017, Quixoticity https://www.quixoticity.com/resources/The_Quixoticity_Index_2017.pdf

[6] ECC Report 199 User requirements and spectrum needs for future European broadband PPDR systems Wide Area Networks), ECC, May 2013

[7] Considerations for Government Authorities when they are planning to acquire Mission Critical Mobile Broadband Services, TCCA, Dec 2015

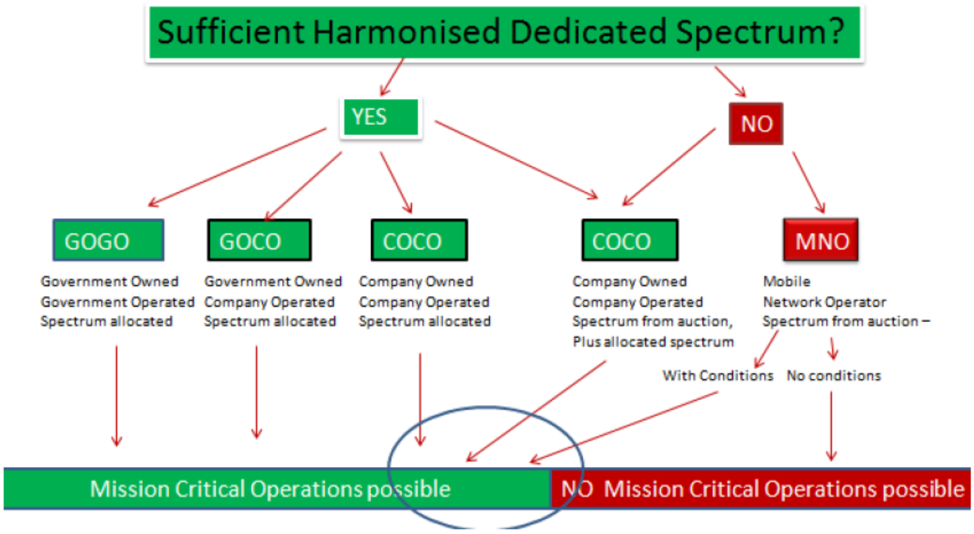

Figure 1: Models for building and operating BB-PPDR network. Source: TCCA

In Figure 2 below, we illustrate what are, in our view, the positives and negatives of a dedicated BB-PPDR network.

Dedicated Network

Positives

- Network management, maintenance and control in hands of the end-users/third party operator. No need to rely upon the robustness and coverage of a mobile operator(s) RAN.
- Can provide optimum level of resilience, reliability and availability compared to other solutions
- Smooth and self-managed interoperability between other services, i.e. mission critical and non-mission critical
- Better control of supply chain and choice of equipment
- Existing Tetra networks are already in place which already have a network configuration and sites, thereby potentially reducing the number of additional sites required

Negatives

- High capital and operational costs due to the need to build a new network or significant upgrade to existing PPDR network infrastructure
- Higher costs for specialised BB-PPDR equipment that uses spectrum that is not widely used in other countries, potentially limiting the ecosystem and economies of scale. Lengthy timescales for building out and commencing operation of a new network from first date of procurement
- Opportunity cost of the allocation and assignment of spectrum to BB-PPDR network provider. Negatively impacting on other spectrum uses for same spectrum.

Figure 2: Positives and negatives of dedicated BB-PPDR network

2.2.2 Support of PPDR applications over commercial cellular networks

The support of BB-PPDR applications using commercial cellular networks is a relatively new concept which has been adopted in a handful of countries (section 3 provides more details of how commercial networks are being used for BB-PPDR in these countries).

The option for supporting BB-PPDR applications over cellular networks has arisen due to enhanced capabilities, features and growing coverage provided over 4G/LTE networks. In many countries, mobile operators have either decided to invest in extending coverage as a competitive advantage or as part of licence conditions when obtaining a particular licence through auction.

CEPT's[8] definition of using commercial network infrastructure for BB-PPDR applications states:

> *…the authority will buy mobile broadband services from commercial mobile network operators. The services are delivered through the commercial mobile network operator's public network and no dedicated network infrastructure is involved in the service delivery to the public safety users. In some countries it may be possible to have a national roaming agreement in place, allowing PPDR terminals to get services from other networks if the currently used one fails or if the user moves out of the coverage of the currently used network.*

There are two variants for this deployment model. These include deployments 'with' special requirements and those without. These variants are summarised below:

- Access with special requirements means the operator provides the BB-PPDR user with prioritised access, or special service with a minimum quality of service
- Access without special requirements means the BB-PPDR users receive the same service as ordinary consumers. We note that this type of approach is currently used by a number of emergency service end users today

The advent of network slicing in future mobile networks with the introduction of 5G technology may enhance the possibilities of access with special requirements. For example, the mobile operator could incorporate a separate slice in its network to support BB-PPDR services.

In Figure 3 below, we illustrate what are, in our view, the positives and negatives of supporting BB-PPDR applications over commercial networks.

[8] ECC Report 218

BB-PPDR over commercial network

Positives

- Already satisfies non-mission critical data communication for PPDR users today
- Has potential to offer mission critical data communications subject to a service level agreement
- Access to wide range of standardised equipment and spectrum bands
- Reduces capital and operational cost and overall management overhead compared to dedicated network including long term savings from lower operational costs as the network is provided as a managed service
- Competitive tender typically used to select the preferred commercial service provider, with control over contract period, renewals, delay penalties and other obligations
- Users do not need access to dedicated spectrum which frees that spectrum up for multiple applications and removes the need for potentially inefficient administrative assignment of the relevant spectrum by regulators
- With appropriate prioritisation, PPDR users can access the (expected) increasing capacity on a commercial service provider's network - commercial networks are designed for a larger number of users and have the potential to increase capacity to meet demands of consumers compared to a dedicated network solution
- Timely provision of PPDR services as commercial service providers have existing network built
- Could contract with more than one commercial service provider (e.g. to improve resilience, coverage)

Negatives

- Lose control of network operation which requires a well-defined service level agreement
- Careful consideration of the specification of the requirements with high risk of too tight a specification i.e. extensive coverage requirements and service level provision may lead to costly and lengthy delivery
- Higher risk of network failure due to potentially lower levels of resilience
- Some additional capital investment costs may be needed to 'harden' the network in certain strategic locations where resilience and availability is paramount e.g. stadiums, metro systems, airports
- One needs to find an MNO(s) willing to provide the service at a reasonable price in light of the desired SLA

Figure 3: Positives and negatives of BB-PPDR network over commercial network

2.2.3 Hybrid solutions

A hybrid solution is defined as a 'combination of dedicated and commercial networks' according to CEPT. There are a number of potential approaches for combining these two types of networks that can vary significantly. We highlight what these are below, as extracted from ECC Report 218:

- *Geographical split between dedicated and commercial network infrastructure;*
- *Mobile Virtual Network Operator (MVNO) model where PPDR users share Radio Access Network (RAN) with the public users;*
- *MVNO model combined with a geographical split;*
- *Extended MVNO model where PPDR have dedicated carriers in the commercial network's radio transmit*ters / receivers throughout the country.

We note the possibility that one or more of these hybrid options could evolve to support network slicing such that the MVNO aspect becomes a network slice as part of an operators 5G network.

We describe each of these methods in more detail below.

Geographical split between dedicated and commercial network infrastructure

This solution is based on augmenting the 4G coverage of a commercial network or networks by building additional dedicated infrastructure for the purposes of PPDR users. A representative diagram of the geographical split is shown in Figure 4 below.

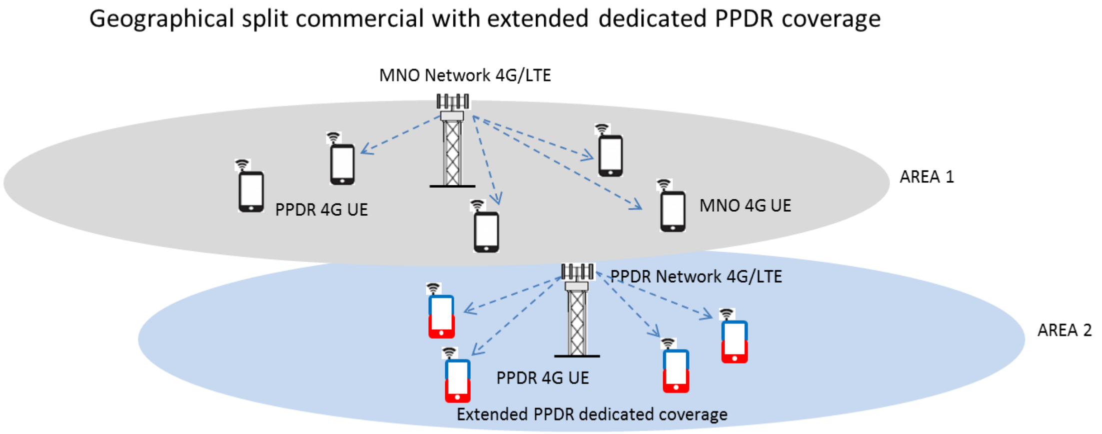

Figure 4: Diagram of geographical split option

The location of the dedicated parts of the network would be dependent on a number of aspects, namely:

1. the requirements of the PPDR users; and
2. the extent of existing coverage and service from the commercial network(s).

For example, 4G networks in most countries have coverage gaps in many rural areas. The map shown in Figure 5 is by way of example demonstrating how the strength of the signal varies by location, reducing in remote areas to an unusable level. It would be in these areas (and other specific locations) that the dedicated coverage may be needed for BB-PPDR.

Figure 5: Example of 4G outdoor coverage map available on ComReg website[9]

Furthermore, it is noted that dedicated spectrum[10] may be needed in this approach for PPDR users and an integrated roaming capability between the commercial and dedicated networks so that seamless operation is possible.

MVNO model where PPDR users share RAN with the public users

An MVNO is a service provider that acquires access to mobile networks at wholesale prices. MVNOs generally acquire very large volumes of data (typically commercial agreements are on 3 to 5 year contracts) from the wholesale mobile operators and then offer their own customers, who may be a particular segment (e.g. international residents or supermarket customers), a range of tariffs (mix of voice and data) in competition with other retail service providers.

The diagram shown in Figure 6 below is for the MVNO model which identifies the PPDR 4G users operating on a public MNO network but with services provided by a PPDR MVNO to the PPDR end users.

[9] https://coveragemap.comreg.ie/map

[10] The dedicated spectrum could be acquired either directly from a regulator or indirectly from MNOs (e.g. via spectrum transfer or leasing)

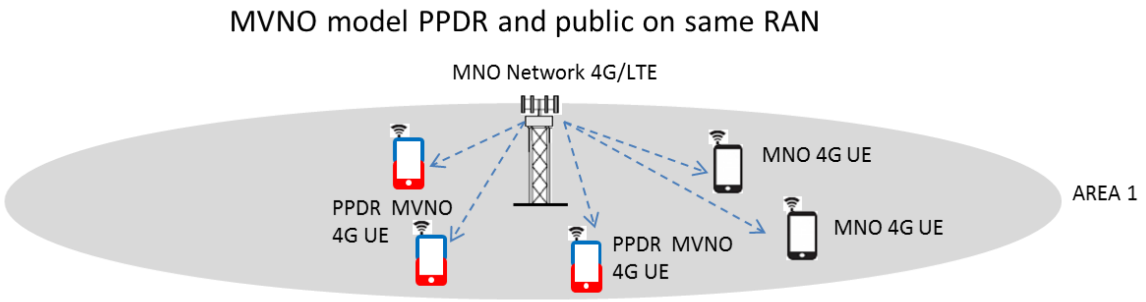

Figure 6: MVNO model

In the case of a PPDR MVNO, the requirements would be more stringent such that an element of control of parts of the core network may be needed, or that PPDR is provided with an interconnection from its own core network. This model allows the PPDR community as a whole to negotiate as a single entity with the service provider to ensure a better deal is agreed rather than individual end-users such as police forces or separate fire brigades.

For this MVNO model approach, PPDR users could use or build their own dedicated core network and integrate their own service model. This would ensure PPDR users retain control of the core network and service offerings. It would only be the RAN part of the network that is shared with public users.

An example of this approach is used in Belgium with the emergency services communications provider Astrid[11]. Astrid is the TETRA network provider for emergency service users in Belgium. It provides national radio communications, paging and dispatching. However, in response to the frustration from users with the lack of mobile broadband, Astrid tendered for an MVNO service for the provision of mobile data services to emergency service users.

As a result of this tender process, the Blue Light Mobile[12] project provides emergency service users with a special Subscriber Identity Module (SIM) card that can be used with their standard mobile device and that provides MVNO features such as:

- National roaming across all Belgian MNOs
- High priority access at all times over normal consumers
- Use of a Virtual Private Network (VPN) to enhanced security
- Access to the Cloud and private Local Access Network (LAN)

MVNO model combined with a geographical split

In this case, the MVNO part is similar to the above model with the exception that in some geographical areas such as major urban centres or along roads, or specific venues, dedicated RAN infrastructure is deployed specifically for the PPDR users. In all other geographical locations, the PPDR services are delivered by the RAN of one or more mobile operators. The diagram in Figure 7 shows the MVNO users in both the MNOs network and operating in dedicated PPDR 4G coverage.

[11] Astrid web site https://www.astrid.be/en/about-astrid

[12] Blue Light Mobile https://www.astrid.be/en/services/blue-light-mobile

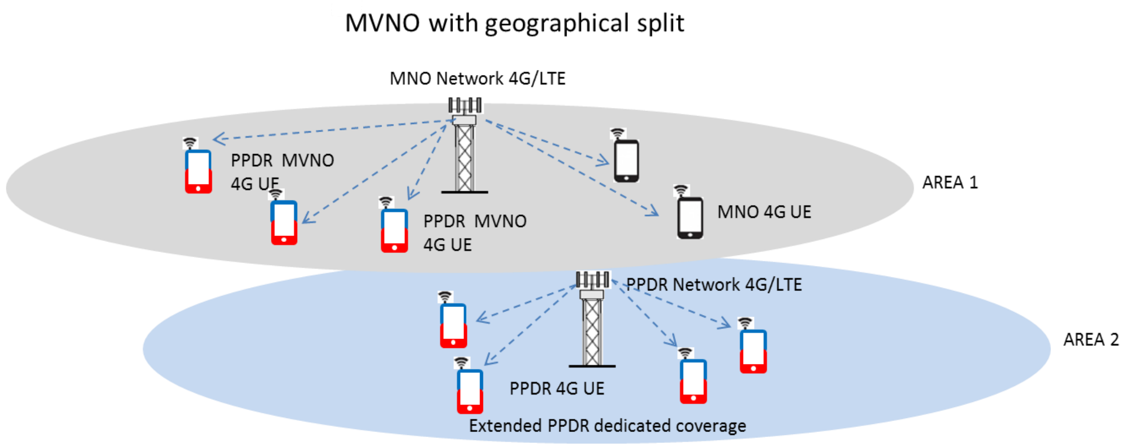

Figure 7: Combined MVNO model with geographical split

Extended MVNO model

This model is similar to the previous two MVNO models such that a dedicated core and service model is built for PPDR users. The exception in this case is the integration of dedicated carriers for PPDR (transmitters and receivers) deployed in the commercial mobile operators RAN (all base stations across the country). This additional flexibility enables the control of dedicated carriers but a reliance upon the robustness and coverage of the mobile operator(s) RAN. We note that dedicated spectrum for PPDR users will be needed for this model.

Figure 8 shows the PPDR users on the MNOs network connected using separate carriers dedicated for providing PPDR services.

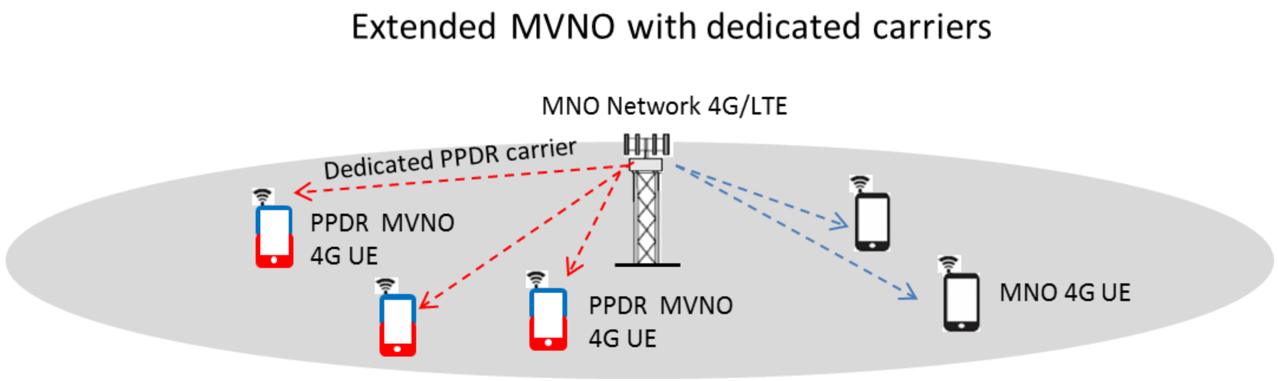

Figure 8: Extended MVNO model with dedicated carriers

The positives and negatives of supporting BB-PPDR applications over hybrid networks are shown in Figure 9.

Hybrid Approach

Positives

- Costs savings can be made from network sharing of both the commercial operators and the dedicated network provider from access to a mix of existing and future planned infrastructure
- A range of varying network integration models which provides a range of commercial options, particularly the MVNO models
- Competitive tender needed to select the preferred commercial service provider increasing the opportunity to achieve value for money

Negatives

- Some models need allocation and assignment of dedicated spectrum
- Some models require network infrastructure build-outs which can be costly and time-consuming to roll out
- Some models rely solely upon commercial network operators RAN infrastructure (coverage and reliability)
- One needs to find an MNO(s) willing to provide the service at a reasonable price in light of the desired SLA
- Potential complexity of combining networks

Figure 9: Positives and negatives of hybrid deployment solutions

In summary, the key benefit of the hybrid model is the choice of a range of options that can suit the national need. Depending on existing factors such as the status of existing PPDR infrastructure, the extent of coverage from mobile operators and availability of spectrum in a particular country, a combination of different options can be selected to suit the specific BB-PPDR requirements, including:

- Priority user MVNO agreement including access to commercial RAN/spectrum
- Extend geographic coverage using a dedicated network and commercial spectrum
- Extend geographic coverage using a dedicated network and dedicated spectrum
- Priority user MVNO agreement with extra carriers for PPDR from dedicated spectrum
- The core network can be used (in the case of a commercial operator), partly controlled or owned by the emergency services within a MVNO network deployment.

2.3 Spectrum options for BB-PPDR solutions

2.3.1 Context and background of spectrum bands for BB-PPDR

For many years now, CEPT, the International Telecommunications Union (ITU), European Commission and European national regulators have been working together to establish harmonised frequency bands for BB-PPDR. Similar to the efforts in deriving the narrowband spectrum bands for PPDR, this approach considers additional requirements to support mobile broadband applications.

One notable recommendation is ITU-R Report M.2009[13] which is the broadband radio interface standard for use by public protection and disaster relief operations in some parts of the Ultra High Frequency (UHF) band. This Resolution recognises the use of spectrum in the range 380 – 470 MHz for PPDR as a core harmonised band.

CEPT, in particular the ECC has a large programme of work that continues to develop a range of decisions and recommendations relating to BB-PPDR spectrum matters[14] which have been published on a dedicated PPDR web portal. In Appendix B we have extracted from the web portal all the relevant ECC Decisions, recommendations and reports and provide a link to each report.

The most notable document is ECC Decision (16)02, which initially identified the 450 – 470 MHz band and the 700 MHz band as candidates for supporting BB-PPDR. Subsequently, in March 2019 the ECC has amended ECC Decision (16)02, and this now includes band options within the range 410-430 MHz for BB-PPDR. This is based on the outcome of the technical studies within ECC Report 283.

This work within CEPT enables European regulators to commence their assessments on the suitability of those bands for BB-PPDR. In particular, it has created a framework of multi-band frequency options for BB-PPDR users across both the 400 MHz and 700 MHz bands enabling the adoption of common technical standards such as LTE.

The list of CEPT reports and recommendations include compatibility studies with adjacent services such as Digital Terrestrial Television (DTT) and commercial mobile networks, international coordination processes, spectrum requirements development and most notably identification of frequency bands for BB-PPDR.

2.3.2 Frequency bands and spectrum options identified for BB-PPDR

In the case of a dedicated network deployment, selecting the right frequency bands for BB-PPDR will be critical. However, there is a need to identify the bands that would be potentially available to suit the required bandwidths needed for BB-PPDR and the respective implications. In particular, ECC Report 218 identifies the concept of flexible harmonisation, which enables the efficient implementation of BB-PPDR within CEPT such that the options can include spectrum from both the 400 MHz and 700 MHz bands. It includes three specific elements, namely:

- Creating a framework for common technical standards (i.e. LTE and its evolutions);
- Enabling national flexibility to decide how much spectrum and which specific frequency ranges should be designated for BB-PPDR networks within harmonised tuning range(s), according to national needs;
- Enabling a national choice of the most suitable implementation model (either dedicated, commercial or hybrid).

[13] ITU-R M.2009 Radio interface standards for use by public protection and disaster relief operations in some parts of the UHF band in accordance with Resolution 646 (Rev WRC-15)

[14] CEPT web site https://www.cept.org/ecc/topics/public-protection-and-disaster-relief-ppdr

Following the update to ECC Decision (16)02, the harmonised frequency bands and spectrum options that can be used for deploying BB-PPDR are illustrated below for the following bands:

- 410 – 430 MHz
- 450 – 470 MHz
- 700 MHz

410 – 430 MHz band plan BB-PPDR options

The spectrum options for BB-PPDR proposed by CEPT Report 218 are illustrated in Figure 10 below.

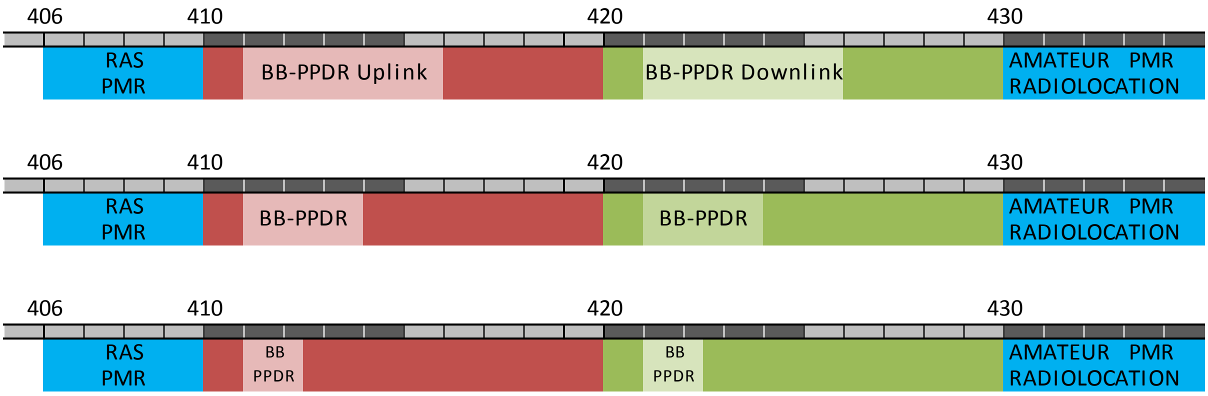

Figure 10: 410 – 430 MHz proposed band plan options for BB-PPDR. Source: CEPT

The uplink portion is in the 410 – 420 MHz range and the downlink in the 420 – 430 MHz range with a duplex spacing of 10 MHz. The figure shown above is indicative, the exact position within the full tuning range of 10 MHz in each duplex portion should be explored by Member States. In practice, this will be restricted to certain sections of the band as there are incumbent licensed users across the full range which may have to be avoided. As an example, the revised draft of ECC Decision 16(02) (at the time of this report) lists the paired frequency bands below:

- 410.0-415.0 MHz / 420.0-425.0 MHz,
- 411.0-416.0 MHz / 421.0-426.0 MHz and
- 412.0-417.0 MHz / 422.0-427.0 MHz.

The quantity of spectrum assigned to PPDR ranges from 5 MHz to 3 MHz and 1.4 MHz. We note that the 3 MHz and 1.4 MHz option, can be placed anywhere within the band (not just towards the lower end as exemplified in the diagram), however, there will likely be restrictions in practice depending on which services are already assigned in the band and to what extent these can be moved or re-farmed.

There is a work item in the Third Generation Partnership Programme (3GPP), however, to standardise parts of the 410 – 430 MHz band for LTE PPDR and PMR/PAMR in Europe. Notably, input documents submitted by Nokia to FM 54[15], present the details of the proposed work item. Furthermore, the 412-

[15] CEPT FM 44 input documents https://www.cept.org/Documents/fm-54/48200/fm54-18-60_new-work-item-3gpp-lte-in-410-430-for-ppdr-and-pmrpamr

417/422-427 MHz range is also under consideration within 3GPP & ECC for Smart Grid and critical IoT applications[16], which is now a potential option for sharing with PPDR at some stage in the future.

This band range is recognised by the CEPT and the ITU[17] as suitable for PPDR and the maximum available spectrum it can support for PPDR is 2 x 5 MHz.

450 – 470 MHz band plan BB-PPDR options

The spectrum options for BB-PPDR proposed by CEPT Report 218 are illustrated in the figure below.

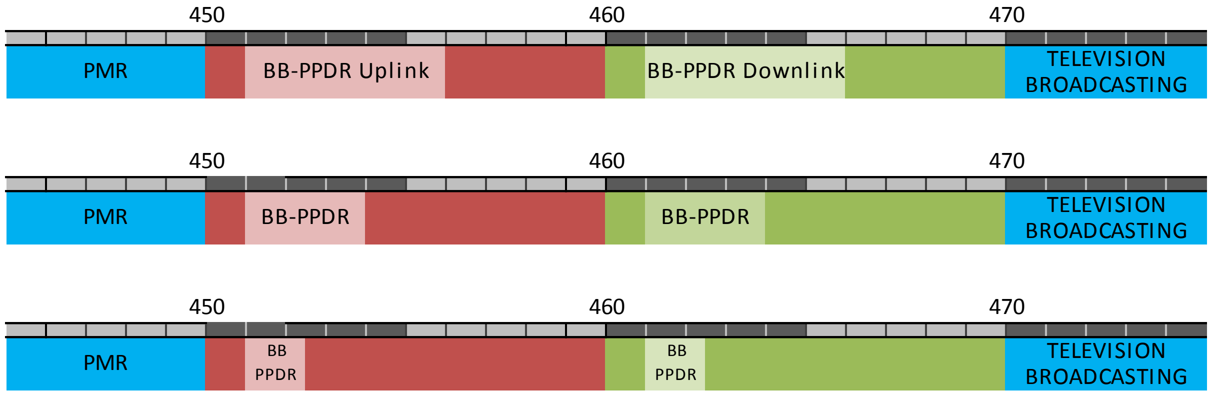

Figure 11: 450 – 470 MHz proposed band plan options for BB-PPDR. Source: CEPT

The figure shown above suggests that the full tuning range of 10 MHz is available in each duplex portion. In practice, this will be restricted to certain sections of the band (not least to protect the international allocation for maritime on-board communications between 457.5125 and 457.5875 MHz). The amended ECC Decision 16(02) lists the paired frequency options below:

- 450.5-456.0 MHz (uplink) / 460.5-466.0 MHz (downlink) and
- 452.0-457.5 MHz (uplink) / 462.0-467.5 MHz (downlink)

It supports the same three bandwidths as the 410 – 430 MHz including 1.4 MHz, 3 MHz and 5 MHz with a 10 MHz duplex spacing. We note that submissions to the consultation on ECC DEC 16(02) suggested making the pairing 2 x 5 MHz rather than 2 x 5.5 MHz as this is in-line with LTE pairing arrangements. The consultation closed in November 2018. The updated amended version of the ECC Decision approved in March 2019 maintains the 2 x 5.5 MHz pairing.

Similar to 410 – 430 MHz, the 450 – 470 MHz supports a number of various incumbent users. Therefore, in practice, this band will be restricted to certain sections of the band as there are incumbent licensed users (e.g. private mobile radio, telemetry) across the full range which may have to be avoided.

[16] Europe Offers Studies of 400 MHz Broadband for Private Mobile Radio for Public Consultation, Nov 2018 https://www.rrmediagroup.com/Features/FeaturesDetails/FID/876

[17] Bands 380 – 470 MHz included in ITU-R Resolution 646 (REV.WRC 15)

This band is recognised by the CEPT and the ITU as suitable for PPDR and the maximum available spectrum it can support for PPDR is 2 x 5 MHz. Below we highlight the two specific variants (for use in Europe) of paired frequency bands, as specified within the 3GPP standards, namely:

- Band 31 (452.5 – 457.5 paired with 462.5 to 467.5 MHz); and
- Band 72 (451.0 – 456.0 paired with 461.0 to 466.0 MHz).

It can be seen that the bands specified in the 3GPP standards fall within the harmonised band options set out by CEPT, except the 3GPP frequencies are arranged in 5 MHz spectrum blocks with sufficient band edge spacing to ensure equipment can be built to meet the unwanted emission masks.

Overall both 400 MHz frequency ranges provide some benefits if adopted for BB-PPDR which include:

- The potential to provide two bands with contiguous bandwidth of up to 2 x 5 MHz.
- Very good propagation characteristics similar to that of existing harmonised narrowband PPDR spectrum thereby minimising the number of additional required sites to replicate nationwide coverage
- The options proposed in each band support standard Frequency Division Duplex (FDD) channelling arrangements
- The use of the guard band in the 450 – 470 MHz would help reduce the risk of interference from BB-PPDR into the upper adjacent band where DTT is used

700 MHz band plan options BB-PPDR options

The 700 MHz band was identified as a band that could potentially support dedicated spectrum for BB-PPDR. The spectrum options derived for 700 MHz were identified by CEPT in ECC Decision (16)02 and the image in Figure 12 highlights the main technical attributes and frequency arrangements in the band which comprises:

- 2 x 30 MHz FDD duplex[18] (55 MHz UL/DL duplex spacing)
- A 25 MHz duplex gap
- A 9 MHz lower guard band
- A 3 MHz upper guard band

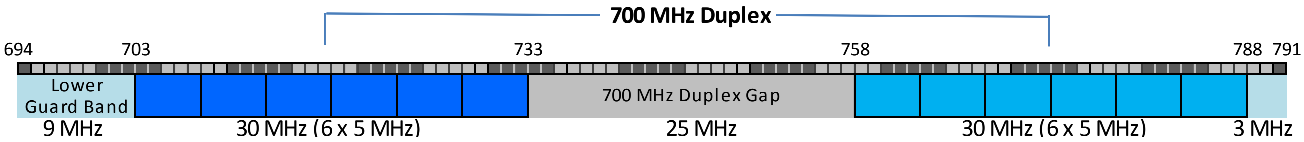

Figure 12: 700 MHz band plan. Source: CEPT

In relation to the arrangements for BB-PPDR, the ECC Decision has identified a range of options that fit into the above core plan. The diagram in Figure 13 below summarises the four key options in which BB-PPDR uplink and downlink could be deployed as dedicated pairs of frequencies (note that PPDR uplink and downlink options are shown in red).

[18] 2 x 30 Duplex aligns with the lower duplexer of the 700 MHz APT plan

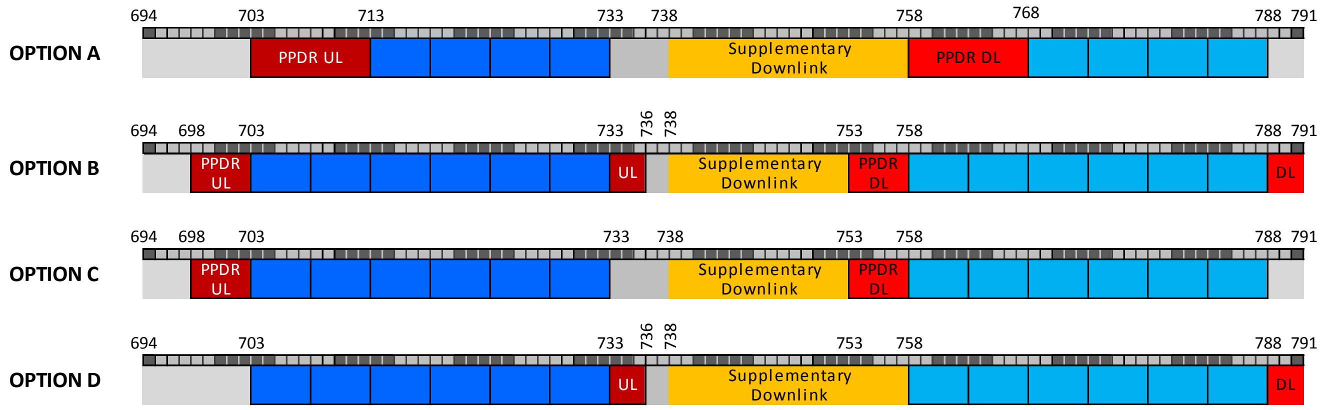

Figure 13: 700 MHz BB-PPDR band plan options. Source: CEPT

The options include a combination, or either one of:

- 2 x 3 MHz: 733 – 736 MHz (uplink) paired with 788 – 791 MHz (downlink) (Option D)
- 2 x 5 MHz: 698 – 703 MHz (uplink) paired with 753 – 758 MHz (downlink) (Option C)

The combination of the spectrum options above achieves a total non-contiguous 2 x 8 MHz of spectrum (Option B).

Alternatively, the following option exists:

- 2 x 10 MHz: 703 – 713 MHz (uplink) paired with 758 – 768 MHz (downlink) this is within the main 700 MHz duplex pairing.(Option A)

These options were derived such that they can accommodate BB-PPDR in the 700 MHz band by either designating spectrum for ***dedicated BB-PPDR use*** or for ***commercial MFCN*** or a combination of the two, which is a ***hybrid approach***.

We note specifically that certain regulatory restrictions would be needed for each of the options to protect adjacent users. For example, the lower guard band is present across all of the options yet for option B and C is only 4 MHz wide, compared to the full 9 MHz for options A and D. CEPT note that with a reduced guard band of 4 MHz, coexistence is possible although localised mitigation would be required in the affected areas[19]. Further, PPDR networks would have a lower density of users compared to subscribers on commercial networks.

In turn, option A designates 2 x 10 MHz for PPDR within the main duplex pair thus reducing the available quantity of spectrum for mobile broadband use to 2 x 20 MHz. Since, mobile operators will typically seek a minimum assignment of 2 x 10 MHz (in 700 MHz), in countries with more than two mobile operators, one or more existing mobile operators might not obtain any 700 MHz band spectrum at award, depending on how it is assigned by national regulators. It could be argued that in countries with more than two operators the spectrum could be spread more thinly between the operators (e.g. that they would not be afforded the opportunity to obtain 2 x 10 MHz each). We discuss the opportunity costs of operators not getting access to this valuable band in section 4.

[19] i.e. where the uppermost DTT channel (686 - 694 MHz) is used.

The other proposed options for PPDR which utilise the guard band (gaps) and the duplex centre gap provide bandwidth (2 x 3 MHz and 2 x 5 MHz) to support mobile broadband applications and fit the standard LTE channel arrangements.

These options have been determined based on extensive compatibility studies produced by CEPT. The specific reports and recommendations can be found in Appendix B. The interference considerations presented in the reports identify some of the compatibility issues such as:

- Third order intermodulation products occurring in the duplex gap of 700 MHz
- Impact of PPDR UL (733 – 738 MHz) interfering with User Equipment (UE)s receiving in the Supplementary Down-Link (SDL) block 738 – 753 MHz
- Interference generated between upper part of DTT in channel 48 and PPDR UL in the 698-703 MHz

We provide more detailed information on the specific interference effects from the compatibility studies in annex B.

However, we understand these compatibility issues have been examined within ECC Report 239 and that there are no significant concerns within the Irish context due to the following mitigating actions:

- PPDR UL into SDL can be addressed by not awarding or restricting the use of the of the interfering SDL block;
- DTT interference is limited to areas of channel 48 use which in Ireland is lightly used[20];
- In areas where the UL is constrained in power, densification of base stations in these areas will ease the UL power constraints

2.4 Spectrum requirements to meet BB-PPDR operational needs

In this section we review the spectrum requirements for BB-PPDR according to the work and studies within CEPT and other organisations such as TCCA.

2.4.1 Definition of BB-PPDR operational needs

It is well understood that the PPDR community has a distinct set of specific operational needs with regards to the provision of communications. For example, it is paramount that the communications network is continuously available 24 x 7 x 365 given the mission critical nature of responding to emergencies by the three main services: police, fire and ambulance.

Historically, the most critical application for first responders was voice communications (and remains the case today) for incidents that required an immediate or urgent response. Secure, reliable, available and robust voice communication has been imperative for users on the ground, on foot, in vehicles, or in the air to satisfy its operational requirements.

Over time the specific operational and critical needs of end users have changed, in line with general consumers of mobile data, and evolved to include a growing demand for specific data-rich applications, more broadly mobile broadband data.

[20] Three sites use channel 48

In addition, the PPDR community recognised the benefits of technology evolution and the increased innovation the likes of 4G/LTE could provide to its capabilities. This is exemplified by the increased use of commercial mobile broadband services by PPDR users[21].

2.4.2 Approach to deriving spectrum requirements

Report ITU-R Report M.2415-0[22] describes the approach to calculating the spectrum needed for PPDR as applied to wide area narrowband and wideband deployments. The report takes a global perspective and incorporates inputs from another ITU-R report (namely ITU-R Report M.2377[23]) which includes the objectives and requirements of PPDR applications using broadband technologies. It also refers to a range of recommendations[24] that have been developed to assist countries conduct spectrum requirement estimations for commercial mobile technologies. It also refers to the work from ECC Report 199 to inform some of the scenarios and spectrum requirements.

In addition, CEPT developed its own approach to deriving spectrum requirements for PPDR specifically for broadband applications. ECC Report 199[6] was published in May 2013 and defines the varying amounts of spectrum needed for BB-PPDR networks against a range of specific PPDR related scenarios. The report provides highly detailed descriptions of the traffic assumptions, applications and functions across the scenarios that inform the final set of spectrum requirements.

The technical user and application assumptions are combined with a set of core operational environments. These mission-critical operational environments were developed so that a range of spectrum estimates could be developed and calculated that cover a minimum set of expected scenarios from typical emergency response situations to major disasters. These environments are specified as follows:

- PP1: day to day operations that could comprise a road accident scenario(s) and “traffic stop” policy operation scenario
- PP2: large emergency and/or public events, e.g. royal wedding in London in 2011 (a pre-planned event) and riots in London in August 2011 (an unplanned event)
- DR (disasters): no particular scenario due to a huge variation in scale of disaster events

User requirements

The user requirements take into account a range of technical inputs and assumptions so that the broadest range of aspects could be addressed as part of the scope of the report. Specifically, the report addresses the network related PPDR requirements to capture the specific needs of PPDR users to fulfil their duties.

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[21] https://www.telstra.com.au/business-enterprise/download/document/business-public-safety-whitepaper-mbb-4g.pdf

[22] ITU-R Report M.2415-0 “Spectrum needs for Public Protection and Disaster Relief (PPDR)”, 2017

[23] ITU-R Report M.2377 “Radiocommunication objectives and requirements for Public Protection and Disaster Relief (PPDR)”

[24] These include recommendations ITU-R. M. 1390, ITU-R M.1768, ITU-R M.1651 and ITU-R SM 1271

The network related requirements refer to the capabilities and features expected to be available from the network including aspects such as:

- system requirements;
- security requirements;
- interoperability;
- cost related requirements;
- spectrum usage and management;
- regulatory compliance;
- planning.

For example, it was assumed that LTE would be the technology used for PPDR networks given it is globally accepted and proven technology, based on harmonised standards and can support economies of scale and benefits of commercial off the shelf equipment/components.

Another key requirement is interoperability between European PPDR organisations which allows the use of a common technology to be used by agencies from different countries to cooperate and communicate effectively.

More details of the user requirements are described in documents produced by the TCCA organisation. One report[25] by TCCA provides a specification which includes the required applications and services for the procurement of mission critical mobile broadband services. For example, it identifies the following types of services:

- Coverage;
- Capacity demands;
- Stability (i.e. dual coverage/no single point of failure);
- List of functional features – voice, data (non-video) and video;
- Network management;
- Software;
- Gateways or other 3rd party connections;
- Security;
- Future upgrades;
- Standards.

BB-PPDR applications

A key input to deriving the overall traffic demand from BB-PPDR users is the types of applications that will be used and supported by the network. Given the need to support broadband applications, a matrix was developed for the ECC report which provides an extensive list of applications categories based on inputs from PPDR studies from a number of European countries including Germany, France, UK, Belgium and the Netherlands. The inputs were reviewed and agreed at meetings of the Radio Communications Expert Group of the Law Enforcement Working Party (LEWP/RCEG) where a final agreed and consolidated list was produced for the report. The main categories included:

- Location data; such as Automatic Vehicle Location System (AVLS);
- Multimedia; such as video feeds of mixed levels of quality and usage (i.e. on location or fixed observation), non-real-time video, photos;
- Office applications such a mobile workspace or access to the internet;

[25] Considerations for Government Authorities when they are planning to acquire Mission Critical Mobile Broadband Services, TCCA, Dec 2015

- Download and upload of operation information, this includes:
  - incident information such as text and images;
  - Automatic Number Plate Recognition (ANPR) list and speed control cameras;
  - download and upload of map data;
  - status information;
- Online database enquiry such as ANPR check, biometric and operational data;
- Other miscellaneous applications including updates of software and mapping data, front and back office applications, paging and traffic management systems.

Table 1 provides some example inputs and parameters that are used to determine the spectrum requirements using the model described in ECC Report 199.

Application	Average per user (kbps)	Multiple simultaneous users	Total traffic (kbps)
UPLINK			
Low quality additional multimedia feeds	64	9	576
Low quality additional multimedia feeds (cell edge)	64	1	64
Fixed video	64	5	320
Low quality additional feeds	11	20	220
Other applications (location, patient monitoring			200
DOWNLINK			
Low quality additional multimedia feeds	64	8	512
Low quality additional multimedia feeds (cell edge)	64	1	64
Other applications (e.g. photos, map download)			300

Table 1: Uplink and downlink applications and usage assumptions for traffic calculation. Source: CEPT

The user requirements and applications related to BB-PPDR requirements form the main inputs into the calculation model that was used to estimate the spectrum requirements.

2.4.3 The spectrum requirements for BB-PPDR as defined by ECC Report 199

We have extracted the spectrum requirements calculated in ECC Report 199. A model was developed by the LEWP/RCEG (see section 4 for definition) which specified the operational environments and used the user requirements and BB-PPDR applications as inputs to calculate the spectrum requirements.

2.4.3.1 The PP1 traffic scenarios

The PP1 traffic scenarios relate to routine day-to-day operations such as a road accident or "traffic stop" scenario. The spectrum requirements, including a low estimate and medium estimate, for both scenarios are given in Table 2 below.

Frequency band	Traffic assumption	Low estimate	Medium estimate
UPLINK			
420 MHz	1 incident "cell edge" 3 incidents near cell centre and background communications	8.0 MHz	12.5 MHz
700 MHz	1 incident "cell edge" 2 incidents near centre and background communications	7.1 MHz	10.7 MHz
DOWNLINK			
420 MHz	1 incident "cell edge" 3 incidents near centre with background communications	7.6 MHz	10.5 MHz
700 MHz	1 incident "cell edge" 2 incidents near centre with background communications	6.9 MHz	9.0 MHz

Table 2: Total uplink and downlink bandwidth requirements for BB data communications. Source: CEPT

The results from the PP1 (day-to-day operation) scenario indicate that for the low estimate (the maximum amount of spectrum needed would be 2 x 8 MHz to satisfy the (uplink) requirements and if just the 400 MHz band was available. The medium estimate exceeds the amount of spectrum that would be available in either the 400 MHz or 700 MHz bands.

In the case of the downlink result from the PP1 (day-to-day operation) scenario, it shows for the low estimate the maximum amount of spectrum needed would be 2 x 8 MHz to satisfy the requirements and if just the 400 MHz band was available. The medium estimate would need more than 2 x 10 MHz if using the 400 MHz band but would be possible to use 2 x 10 MHz if using the 700 MHz band.

We discuss in section 4 how much spectrum is needed for BB-PPDR specific to Ireland and which bands would be most suitable.

Furthermore, the report indicates that given the 400 MHz band provides wider coverage compared to 700 MHz, there is the potential for an increased number of incidents within a given area to occur, thus causing higher throughput. Overall the report indicates that 10 MHz would be sufficient in both the uplink and downlink to support the PP1 scenario if just the 400 MHz band was available. However, careful network planning would be needed.

2.4.3.2 The PP2 traffic scenario

The PP2 traffic scenarios relate to a large emergency and/or public event, the example used is that of the Royal Wedding in London in 2011 (which was a pre-planned event) or the riots in London in August

2011 (which was an unplanned event). The spectrum requirements, including a low estimate and medium estimate, for both scenarios are given in Table 3 below.

Frequency band	Traffic assumption	Less stringent case	Worst case
ROYAL WEDDING			
Independent of frequency band	PP2 traffic scenario with background communications	10.3 MHz	14.3 MHz
LONDON RIOTS			
Independent of frequency band	PP2 traffic scenario with background communications	5.8 MHz	7.8 MHz

Table 3: Broadband data communications results for PP2 traffic scenarios

The more demanding PP2 (major event) traffic scenario drives spectrum requirement estimates above 10 MHz, although the lower estimate is only marginally above 10 MHz.

The report notes that for the planned event, additional capacity could be added in advance by using temporary infrastructure[26] and thus the additional capacity could be offloaded from the core network. The report therefore concludes that *10 MHz of spectrum for the uplink and another 10 MHz for the downlink* is sufficient to meet the core requirements of the PP2 scenario. Although situations can occur that would exceed the capacity of the permanent network.

2.4.3.3 DR (disasters)

Finally, the results from Report 199 indicate that the spectrum requirements for the disaster (DR) environment would be of the same magnitude as that for PP2 scenario above, i.e. 10 MHz for downlink and 10 MHz for uplink. This is based on the consideration that there are similarities in terms of wide geographical areas and that this will involve the same number of users using similar applications. Therefore the spectrum estimate for PP2 covers the early needs of a DR event (noting that this is a simplifying assumption).

2.5 Summary of review of relevant material for BB-PPDR spectrum and deployment options

In summary, we consider that CEPT and TCCA in particular have developed authoritative and informative reports and recommendations that enable regulatory authorities to understand the technical, regulatory and practical implications for implementing BB-PPDR systems throughout Europe. Many of the reports and documents provide comprehensive definitions and descriptions of aspects such as the network deployment options, highlighting the pros and cons of each approach, spectrum options and spectrum requirements.

[26] This assumes the frequency can be in the same spectrum as the PPDR network or another frequency band in accordance with CEPT harmonised bands for PPDR

More specifically, we have found:

- There are 3 network deployment models (Dedicated, Commercial and Hybrid) for consideration in the context of BB-PPDR implementation indicating the increased flexibility and capability in network deployment
- 2 x 10 MHz has been identified as a sufficient amount of spectrum for BB-PPDR by CEPT and other organisations to support the end user applications within certain usage scenarios and expected type of deployments.

In addition, CEPT has developed a number of studies and recommendations that have clearly identified the two 400 MHz bands (410-430 MHz and 450 – 470 MHz) as prime candidates to support future dedicated BB-PPDR networks. Similarly, extensive work has been conducted to examine the potential use of the European 700 MHz band plan, identifying the four options for deploying dedicated BB-PPDR spectrum. However, there are issues to consider in practice regarding the specifics of identifying available quantities of spectrum that can be allocated for BB-PPDR use.

Lastly, ECC Report 199 provides a range of authoritative technical inputs and parameters and an approach to calculating the spectrum requirements for BB-PPDR. The LEWP model that is used is based on actual events, that require BB-PPDR communications and considers the number of devices, simultaneous usage, range of applications and overall intensity of the communications environment, thus, providing a robust set of results.

We use the LEWP model later in section 4 to calculate spectrum requirements for the Irish context taking into account BB-PPDR utilisation.

3 International situation

3.1 Introduction

In this section, we provide a concise but comprehensive overview of the past, present and proposed future approaches to PPDR spectrum and services in 15 European countries. We study the most recent mobile narrowband and broadband PPDR technology choices for these markets, as well as the deployment models and spectrum allocations for public safety networks and services. We also present summary charts for these European markets in a colour-coded format which helps visualise the different status and trends of PPDR models and spectrum allocation in the main sub-1 GHz bands. It is important to remember that the PPDR services, deployment model and spectrum allocation in each of these countries are influenced by each country's national circumstances, which will differ to various degrees from the national circumstances of Ireland.

3.2 Methodology

Within the specialised area of PPDR communications, the global market is moving from largely closed, dedicated, narrowband, voice-based solutions towards a future generation of more open, hybrid (a complex mix of dedicated and commercial), broadband, rich multimedia solutions. This becomes more achievable with advancements in 3GPP standardisation which open up new possibilities for deploying PPDR over the same network infrastructure as commercial networks using for example, Software Defined Networking (SDN) and Network Functions Virtualisation (NFV). While a range of PPDR models (see chapter 2) can be used to deliver the solution for PPDR, this move requires the allocation of spectrum, engagement with global standards processes such as 3GPP and much closer coordination among national and international organisations and associations than ever before. A growing number of administrations around the world are on this journey from the past to the future. For those Governments and public safety communities now considering their PPDR solutions, important lessons can be learned from these other countries and certain trends are beginning to emerge.

We have conducted interviews with representatives from Governments, associations, industry and subject-matter experts during January 2019 in order to collect the most relevant information.

Where gaps have remained or inconsistencies have been found, we also accessed secondary sources of information and documentation. Wherever possible, especially in the case of noted opinions and forecasts, and when time has allowed, we have searched for at least 2 sources of information to corroborate or refute the information or data we have collected.

The following authorities, organisations and companies provided valuable information for this study:

- Austrian Ministry of Interior (Austria)
- ASTRID NV/SA (Belgium)
- European Utilities Telecom Council (EUTC) (Belgium)
- Suomen Erillisverkot/VIRVE (Finland)
- French Ministry of Interior (France)

- AGURRE (PMR Large Users Association) (France)
- BDBOS (German Federal Agency for Public Safety Digital Radio) (Germany)
- Pro-M Zrt. (Hungary)
- Dutch Police/C2000 (Netherlands)
- DSB (Norwegian Protectorate for Civil Protection)/Nodnett (Norway)
- Telekom Slovenije (Slovenia)
- Ice Group (Sweden)
- MSB (Swedish Civil Contingencies Agency)/RAKEL (Sweden)
- Geneva Police (Switzerland)
- UK Home Office/ESMCP (Emergency Services Mobile Communications Programme) (UK)
- DCMS (Department for Digital, Culture, Media and Sport) (UK)
- Ofcom (Office of Communications) (UK)
- Joint Radio Company Ltd. (JRC) (UK)
- The Critical Communications Association (TCCA) (UK)

3.3 Selected European Countries

Although there has been some degree of standardisation and harmonisation of spectrum and technology choices in the area of public safety/PPDR communications across Europe, many national and regional differences still remain, which means that it is unlikely one single approach will be taken by all European nations.

In this section, we have therefore decided to study as wide a range as possible of European nations' approaches to public safety/PPDR network deployment and sub-1 GHz spectrum options. Fifteen countries were identified and have been documented below.

3.3.1 Austria

Austria has been rolling out regional TETRA networks since 2006, with a final nationwide TETRA coverage completion date of 2019. The Austrian TETRA network is privately owned, but operated and managed by the Ministry of Interior. Due to recent investment in TETRA, existing networks are likely to remain operational for at least another decade.

The Federal Ministry of Transport, Innovation and Technology (BMVIT) drew up a national roadmap for the 700 MHz frequency band in 2017[27]. The main band will be made available for wireless broadband communications services from June 30th, 2020. Regarding PPDR, 2 x 8 MHz of dedicated spectrum in the 700 MHz guard bands (2x3/2x5) has been reserved for PPDR and could be used if requested by the relevant authorities, if real demand exists beyond existing TETRA services and if the band is

[27] BMVIT, Austria: National Roadmap 700 MHz Frequency Band https://www.bmvit.gv.at/en/telekommunikation/roadmap_700mhz.html

harmonised across Europe, especially by border countries and other significant markets such as Germany, France, Switzerland and Italy.

Similarly, no plans have yet been drawn up to provide PPDR services in UHF bands (410-430 MHz, 450-470 MHz). Such plans would take into account similar factors for the 700 MHz guard bands and the Duplex Gap.

3.3.2 Belgium

Belgium built one of the first nationwide public safety TETRA networks anywhere in the world. An independent, Government-owned operator, ASTRID[28], was set up in 1998 with operations beginning in 2001. More recently, ASTRID reached an agreement with Belgian MNOs – including a priority agreement with Proximus – to provide a non-mission-critical broadband data service, Blue Light Mobile using multi-SIM terminals to complement TETRA voice service[29]. After the Brussels terrorist attacks in March 2016, ASTRID implemented both operational and technical improvements to its network, while the Belgian Government also began studies into future PPDR requirements.

The Belgian Government has taken the decision to auction the main 700 MHz band (2 x 30 MHz FDD) to commercial operators, although a failure to agree how the money raised should be distributed and with new federal elections approaching, the process has now been further delayed until 2020 at the earliest[30]. The focus for the 700 MHz band will be the launch of 5G services. There is already very high population coverage for current 4G services, with Proximus[31] and Orange[32] already passing 98% population coverage.

A draft Royal Decree[33] published in 2018 stipulates that at least one mobile network operator acquiring spectrum in 700 MHz must support Mission Critical Push-to-talk (MCPTT) services with fair pricing, terms, conditions and priority access to emergency services. In the Belgian regulator's (BIPT's) communication[34] on 5G, it notes that Band 68 & Band 28b (700 MHz guard bands, 2 x 8 MHz) are harmonised for PPDR. BIPT states that it will be possible to exclusively reserve Band 68 (2 x 5 MHz) for use by ASTRID for a dedicated network. It further notes that ASTRID will be able to use the mobile operators' public systems, as provided for by the draft Royal Decree where a system of national roaming is proposed to this effect. Overall, BIPT expects ASTRID to make complementary use of a combination of access to the existing mobile networks and access to one of its own networks (e.g. for rural areas, direct mode operation, ground-air communications, ...).

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[28] https://www.astrid.be/en

[29] Please also see section 2.2.3. MVNO Model for further details.

[30] Conversation with ASTRID and Belgian 5G auction pushed back to 2020, telecompaper, Jan 2019; www.telecompaper.com/news/belgian-5g-auction-pushed-back-to-2020--1276803

[31] 4G everywhere – Proximus website, https://www.proximus.be/en/id_cl_4g/companies-and-public-sector/discover/quality/4g-for-your-business.html

[32] Orange Belgium has increased its 4G coverage in the Walloon region, Intelligent CIO, June 2018, http://www.intelligentcio.com/eu/2018/06/19/orange-belgium-has-increased-its-4g-coverage-in-the-walloon-region/

[33] Belgium: IBPT, "Communication du Conseil de l'IBPT à la demande du Ministre des Télécommunications du 13 août 2018 concernant le Projet de Réglementation pour la Mise aux enchères multibande" , August 2018

https://www.ibpt.be/public/files/fr/22572/Communication_projet_reglementation__encheres_multibande.pdf

[34] Communication by the BIPT Council of 10 September 2018 regarding the Introduction of 5G in Belgium, BIPT, 2018,

https://www.bipt.be/public/files/en/22601/2018-09-10_5G_EN.pdf

From conversation with ASTRID, we are informed that it plans to develop a full MVNO model, maintaining control over emergency services subscribers and potentially filling in coverage gaps with its own sites if necessary.

ASTRID is also the lead critical communications operator for the Pan-European BroadWay programme that is procuring a harmonised, cross-border solution based on 5G.

3.3.3 Bulgaria

Bulgaria commissioned one of the earliest TETRA networks in Eastern Europe during the late 1990s, to cover its south-eastern border upon accession to the European Union. In 2017, the country announced a major upgrade to its nationwide TETRA network allowing the national operator to integrate smartphone users into its TETRA group calls via an MVNO-style arrangement, similar to services provided by TETRA operators in Belgium (ASTRID) and Finland (VIRVE)[35].

Bulgaria developed a national roadmap in 2017[36] for the release of frequencies in the 700 MHz and 800 MHz bands for future 5G services. 2x20 MHz (703-723/758-778 MHz) will be made available for 5G, with mobile operators potentially offering PPDR services in these bands. Dedicated spectrum in the lower 2x5 MHz (Band 68) will also be made available for PPDR services.

Any future decision made regarding PPDR in 400 MHz bands would depend on a request from the relevant authorities, significant demand for additional spectrum in lower frequencies and future ECC decisions and deployments in major European markets for IoT/M2M, Smart Grid, etc.

3.3.4 Czech Republic

The Czech Republic took the decision during 1990s to deploy Tetrapol technology for public safety communications, with a series of regional networks being upgraded to create a nationwide network. Although Tetrapol is a highly secure voice communications solution, it never became a European or global standard technology and has limited data capabilities due to its narrowband FDMA technology.

In January 2019, the Czech regulator, CTU, released revised guidelines[37] for the 700 MHz auction, where 2x30 MHz (703-733 MHz (UL); 758-788 MHz (DL)) will be made available for mobile services via auction no later than June 30th, 2020. This includes two blocks of 2 x 5 MHz and two blocks of 2 x 10 MHz. During the first stage of the auction process, 2x10 MHz will be reserved for a new entrant. The remaining auction conditions require *network development criteria for the winners of the auction, the obligation to provide national roaming, the obligation to enable PPDR communication and the requirement to prevent interference with the digital terrestrial broadcasting.* [38].

Due to these arrangements for PPDR, the Czech Republic has not yet considered the 700 MHz guard bands for dedicated PPDR spectrum. However, in mid-March 2019, Nordic Telecom recently

[35] Please see sections 3.3.2 and 3.3.6 for further details of these MVNO arrangements. Bulgaria has the same TETRA equipment supplier – Airbus SLC – as Belgium and Finland, allowing it to deploy a tried and tested hybrid solution.

[36] Dimitar Dimitrov, MTITC, Bulgaria: "Bulgarian Strategy and Policy for 5G", ITU Meeting, 2018.

[37] Jan Cisar, Cullen International January 2019

[38] Czech Republic updates draft principles for 5G auction, Jan 2019, https://www.martes-specure.com/blog/czech-republic-updates-draft-principles-for-5g-auction-48

announced[39] the development of an LTE network for critical communications in the newly harmonised 410 - 430 MHz band.

3.3.5 Denmark

DBK, a Motorola Solutions subsidiary, has built a nationwide TETRA network for Danish public safety. There are approximately 25,000 users with 99.5% geographical coverage[40]. DBK delivers the TETRA network as a managed service in return for a monthly fee, subject to strict service level agreements (SLAs). Any broadband PPDR network wishing to replace the TETRA network would have to achieve at least comparable coverage.

The Danish Government agreed a new Telecoms Policy in May 2018[41] with a strong focus on digital growth and a new enhanced national broadband strategy. Motorola Solutions proposed 2x10 MHz (713-723/768-778 MHz) be assigned to a dedicated PPDR network. The Government decided[42] to auction all 2x30 MHz as well as 20 MHz unpaired in the duplex gap by open auction with long-term geographical coverage requirements that are comparable to those of existing public safety networks. The Danish Energy Agency announced the completion of the award on the 28 March 2019[43] where all 2 x 30 MHz of spectrum was assigned to existing MNOs.

No decision has yet been made in Denmark regarding the 700 MHz guard bands (Band 68 & 28b). Danish network operator, Net1, launched LTE in 450-470 MHz (Band 31) in 2015 and by 2018 claimed to have reached 98% geographical coverage[44]. Operators across Scandinavia are either already providing limited broadband services or lobbying to do so. There is a good opportunity for this band to be more widely used for PPDR especially in more remote areas.

We further note that in Denmark, the Danish Energy Agency (DEA) tasked Analysys Mason, in November 2017, to consider the potential use of spectrum in the 700 MHz band for PPDR[45]. In its report, Analysys Mason noted that, *"the model output shows that the costs of a dedicated network solution is significantly higher than the costs of using a commercial mobile network",* and that *"from an economic cost perspective, providing a broadband PPDR over a commercial mobile network appears more attractive*" than using a dedicated network.

3.3.6 Finland

Finland has one of the world's most advanced PPDR ecosystems with a wide range of operators, equipment manufacturers and solution providers working together to develop integrated mission-critical solutions. A Government-owned, independently-operated network, Suomen Erillisverkot, has been running the nationwide VIRVE TETRA network for all emergency services since the 1998- 2002 roll-

[39] Nordic Telecom develops LTE network for critical communications, Mobile Europe, March 2019https://www.mobileeurope.co.uk/press-wire/nordic-telecom-develops-lte-network-for-critical-communications

[40] Motorola Solutions, Case Study, Denmark's Nationwide TETRA Network, 2012

[41] Danish Energy Agency – Danish Ministry of Energy, Utilities and Climate, 2018

[42] Danish Energy Agency web site https://ens.dk/en/our-responsibilities/spectrum/auctions

[43] https://presse.ens.dk/pressreleases/flere-steder-i-landet-kan-se-frem-til-bedre-mobildaekning-2853575

[44] Net 1 web site www.net1.dk/

[45] Award of 700MHz, 900MHz and 2.3GHz spectrum in Denmark – spectrum for PPDR use, Analysys Mason, November 2017, pp30

out. Energy services in Helsinki and other major cities also use VIRVE. Finnish Railways have also recently switched from GSM-R to VIRVE TETRA.

Finland was also one of the first countries in the world to develop a full plan[46] – the five-step plan - to migrate from TETRA to next-generation broadband solutions based on 3GPP standards. Responsibility for emergency services communications was switched from Ministry of Interior to Ministry of Finance during 2017, with a task force set up to study spectrum, organisational and operational issues and any legislation required to help the switch to broadband PPDR. In 2016, 2x30 MHz of the 700 MHz band was awarded to the mobile operators via auction[47].

VIRVE 2.0 will continue to operate as a full, extended MVNO, taking service from all mobile operators under legislation[48] that enables national roaming, with its own core and network management system, building out additional sites as required in more remote areas of Finland[49]. Prioritised PPDR subscriptions will be available during 2020; mission-critical apps will be available in 2021; migration to VIRVE 2.0 service will begin in 2022, with the expectation of a DevOps model being implemented by 2025, when the TETRA network will be fully decommissioned.

Finland shares a 1,340 km EU border with Russia, which still uses the 700 MHz band for broadcasting services, so it has been decided that the 700 MHz band is not suitable for PPDR services across large parts east of the country. Ukko Mobile launched a 450 MHz LTE network in 2014[50] which claims has almost 100% population coverage and the best geographical coverage of any mobile operator in Finland. However, at a recent company Extraordinary General Meeting it was announced[51] that the Finnish State Council reduced the 450 MHz licence coverage obligation from 99% to 35%, to become a local micro private network operator – to save costs and increase value of the licence. Therefore, any interest in access to the UKKO network by VIRVE 2.0 has diminished and thus will continue to seek access to all Finnish mobile operator frequency bands (including 5G bands) under national roaming conditions.

3.3.7 France

During the 1990s, the French Government took the decision to develop its own critical communications technology: Tetrapol, a publicly available specification now maintained by Airbus SLC in VHF (80 MHz) and UHF (380-400 MHz). The INPT – nationwide shared public safety -network is now used by all major first responder organisations[52].

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46 Explained in many documents, including: http://www.securelandcommunications.com/hubfs/pdf/VIRVE_Hybrid_Network_Success_Story.pdf

47 Information in this paragraph and the next based on an interview with Suomen Erillisverkot/VIRVE and the Presentation entitled: "VIRVE 2.0: Broadband Mission Critical Communication

48 https://www.cullen-international.com/product/documents/FLTEFI20160001

49 We note that migration to VIVRE 2.0 by 2022 in Finland will be to support 3GPP Mission Critical service but no mention of specific frequencies http://5gaa.org/wp-content/uploads/2019/02/7.-PSCE_ActivityTracking_120219.pdf

50 See Ukkerverkot web site for details www.ukkoverkot.fi/

51 Statement by the board of directors on events occurring after the latest financial statements having an essential effect on the state of the company, UKKO, Dec 2018, https://47pp0zfmkum3j73xuaq8o465-wpengine.netdna-ssl.com/wp-content/uploads/2018/12/Ukkoverkot-Oy-Statement-by-the-Board-of-Directors-12.12.2018.pdf

52 For example, see:

Tetrapol has very limited data capabilities and is rapidly reaching end of life, so the French Ministry of Interior has taken the lead in moving towards the next generation of critical communications with a number of initiatives. Paris will host the 2024 Olympic Games by which time 5G services are expected to be in place. This is also the expected date for the final Tetrapol switch-off. The Ministry of Interior set up a specific unit, Future Radio Network[53] (RRF in French) to oversee all aspects of the migration from Tetrapol to future LTE/5G PPDR solutions.

France was one of the first European countries to auction all available 2 x 30 MHz in the 700 MHz Band 28 for mobile services in late 2015. It was also the first country to allocate 2x8 MHz (2x5 MHz in 698-703/753-758 MHz and 2x3 MHz in 733-736/788-791 MHz) for a dedicated PPDR network during early 2016[54], with studies undertaken to evaluate potentially shared spectrum requirements together with all Government and critical national infrastructure providers that could benefit PPDR due to greater economies of scale and coordination with other critical sectors. Government and PPDR have already enacted exemptions from broadcasting services to trial tactical "bubble" networks or small experimental networks in specific geographical areas.

The French Ministry of Interior has offered a number of contracts (Lots) to the private sector to provide advanced PPDR services, including a main contract to mobile network operator, Orange, to explore ways of allowing PPDR users to have priority access to commercial spectrum during emergency situations. 2x8 MHz in 700 MHz is not considered sufficient by French authorities[55] to cover all PPDR needs for mission-critical voice, data and video services in the future, so options in UHF bands (410-430 MHz and 450-470 MHz) are also being pursued.

3.3.8 Germany

Germany started planning a nationwide public safety network during the late 1990s, but a final agreement took several years due to the need for all 16 Länder to agree full terms and conditions such as organisational structure, funding etc. In 2005, a contract was awarded to build a nationwide TETRA network, with a Federal Agency for Public Safety Digital Radio (known by its German acronym, BDBOS) set up to oversee the project[56].

The BDBOS network is now comfortably the largest TETRA network - in terms of numbers of subscribers and quantity of base stations[57] - to be found anywhere in the world. Completed as recently as 2016, it covers over 99% of German territory, boasts 99.95% availability, includes close to 5,000 base stations and over 800,000 users. Such a massive investment in TETRA means that Germany needs to guarantee a reasonable return on investment over at least another decade, meaning that the TETRA network will remain operational until at least 2030. The network is currently undergoing a full

www.securelandcommunications.com/customerstories/inpt-nationwide-public-safety-network-in-france

[53] For example, see: snir.fr/images/pmr-2018/VILLEBRUN-MinInt.pdf

[54] Quixoticity Index 2017, p.2

[55] France Allocates 700 MHz Spectrum for PPDR LTE, Aims to Add 400 MHz in Future, RRC, Feb 2016, https://www.rrmediagroup.com/Features/FeaturesDetails/FID/642

[56] All relevant information about BDBOS can be found at: www.bdbos.bund.de/EN/Home/home_node.html

[57] As mentioned in 3.3.13, Sweden has the largest TETRA network by km^2 of geographical coverage

nationwide upgrade to IP transmission as Deutsche Telekom is cancelling its legacy E1 transmission systems[58].

The Federal Ministry of Interior will coordinate the future evolution of public safety broadband working closely together with the 16 Länder (regional Governments). Germany is still in the early days of making any final decision on PPDR deployments. A pilot LTE network will be set up first to test out full financial, technical and organisational implications. Germany was the first European nation[59] to award 2 x 30 MHz in the 700 MHz band in 2015[60]. The national table of frequency allocation in Germany identifies the additional 2x5 MHz / 2x3 MHz[61] to be for the functions of the BDBOS / Military. If BDBOS decides to deploy in the 2x5 MHz / 2x3 MHz portion it would need to present its plans to the regulator. We understand that some early feasibility studies are being undertaken.

BDBOS is exploring spectrum options that would give 2x10 MHz, including within the 400 MHz band. Outside of the 700 MHz band, BDBOS has indicated a preference for the 450 MHz Band. 2x4.7 MHz is already shared with utilities in this band. BDBOS is aiming for a final decision and implementation of a public safety broadband network by 2025, having become active in the relevant global standardisation bodies including 3GPP, ETSI, GSMA, NGMN etc. developing future 5G user requirements. BDBOS will also be pursuing spectrum at higher frequency bands for tactical networks and other specialised services.

3.3.9 Hungary

Hungary currently has a nationwide TETRA network operated by Pro-M Professional Mobile Radio, a subsidiary of Magyar Telekom, itself a subsidiary of Deutsche Telekom T-Systems. Pro-M[62] is responsible for the implementation and operation of the Unified Digital Radio Communications System (EDR) which provides service to all major emergency services across Hungary. The Ministry of Interior conducted a full review in 2014, leading to a major modernisation programme which began in 2015 – including the switch to an IP-based network and full upgrade of dispatcher stations and network management - which has prepared Pro-M and emergency services for the next stage of development[63].

The National Media and Infocommunications Authority (NMHH) proposes to deploy a dedicated network by providing additional bandwidth for BB-PPDR services with 2x8 MHz and some more in the 400 MHz band (especially in the 410–430 MHz range and/or in the 450 MHz band)[64], in addition to the 2x30 MHz to be made available for award for MFCN in the 700 MHz frequency band. The Government will select the deployment model and NMHH shall provide the required spectrum for the selected model. The preferred options for dedicated spectrum are in the UHF bands studied in ECC Report 240. Although recent trends confirmed during the research conducted for this report appear to suggest a preference for PPDR services in 450-470 MHz and 410-430 MHz for utilities in those European countries where

[58] E1 is a digital transmission link with a total transmit and receive rate of 2.048 Mbps (2048000 bits per second) used in Europe.

[59] Germany kicks off Europe's first 700MHz auction, Telegeography, May 2015, https://www.telegeography.com/products/commsupdate/articles/2015/05/29/germany-kicks-off-europes-first-700mhz-auction/

[60] No special conditions were applied in relation to the provision of PPDR services

[61] https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/Frequenzplan.pdf;jsessionid=DE433A2EE84A6018C65D1DC16E50C070?__blob=publicationFile&v=11

[62] Visit the Pro-M website for more information, https://english.pro-m.hu/About/

[63] Information provided during an interview with Pro-M

[64] NMHH National Roadmap 20 August 2017 http://english.nmhh.hu/document/190192/uhf_vhf_3_national_roadmap_eng.pdf

such options are available, Hungarian authorities are considering both 410-430 MHz and 450-470 MHz for public safety. For this reason, Hungary is supporting additional technical studies in 410-430 MHz[65].

During a specialised EDR Day conference in November 2018, Pro-M declared that its current preferred option beyond 2020 is to maintain its TETRA network, adding broadband LTE services over 450-470 MHz. It does not rule out operating as an MVNO in the 700 MHz band when 5G services are made available at some point in the future[66]. This could enable the creation of a network slice for a PPDR service.

3.3.10 Netherlands

During the 1990s, the Netherlands was one of the early countries to adopt TETRA as its national public safety communications standard to replace around 100 disparate analogue networks, although it was not until 2004 that this unified network – C2000 – actually started to be rolled out. In 2009, there were 3 major incidents where emergency services experienced communications problems, leading to a "C2000 Improvement Project" led by Ministry of Justice and Security[67].

Although Dutch Police were one of the main drivers for European-wide studies into next-generation public safety networks during the early 2010s, the decision was taken in 2014 to replace the existing C2000 TETRA network with an updated TETRA network, with an award for infrastructure made to Hytera Mobilfunk in 2015. As late as September 2018, the Ministry of Justice and Security announced that the C2000 renewal had been delayed yet again, with maintenance taking place on the original TETRA network during early 2019.

The new TETRA contract will run for a further 8-10 years until late 2020s. Each Dutch official already uses a smartphone, so it has been agreed that commercial LTE services will be used for non-mission-critical data, while TETRA will be the primary network for mission-critical voice.

The deployment model for public safety mobile broadband has still not been decided; nor has it been decided if dedicated spectrum will be made available for public safety. The main 700 MHz band (2 x 30 MHz) will be auctioned in 2020 to the commercial sector as a primary 5G band with coverage conditions for successful operators in line with EU directives. The Netherlands has shown interest in the 700 MHz guard bands and duplex gap (2x5/2x3 MHz), but a final decision will depend on decisions made at a European level, especially in larger markets such as France and Germany. The 400 MHz bands are currently heavily used by narrowband PMR.

3.3.11 Norway

Due to quite extreme geographical and demographic challenges, Norway took a decade to roll out its nationwide TETRA network - Nødnett - between 2006 and 2016, deploying over 2,000 base stations and covering 372 tunnels for 60,000 emergency services users. Nødnett's daily operations and maintenance have been outsourced to the private sector with a contract running until the end of 2026, with overall responsibility residing in the Norwegian Directorate for Civil Protection (DSB) [68].

[65] NMHH, "PPDR Applications in Hungary – Future Plans: BB-PPDR Spectrum Regulation" (Presentation – 2018)

[66] Private notes taken during EDR Day, November 15th 2018

[67] Information in 3.3.10 based on an interview with C2000 Project Manager

[68] DSB Norwegian Directorate for Civil Protection, "Alternatives for mission-critical services in public mobile networks in Norway" May 2018.

Norway was one of the few countries to add TEDS (TETRA Enhanced Data Service) to one-third of its base station sites[69], although the service was never activated. Having faced extremely high per-user infrastructure costs during its deployment, the on-going budget for Nødnett was significantly reduced in 2016.

In Norway, based on a study conducted by Nexia Management Consulting (now Analysys Mason) and Manon Business Economics[70], the Norwegian Communications Regulatory Authority (Nkom) recommended that all 2 x 30 MHz of spectrum in the 700 MHz band be made available for commercial public mobile services. Nkom also indicated that the broadband service needs for PPDR-users and the Norwegian Armed Forces can best be met by commercial operators in public mobile networks, and expects that the 700 MHz band will be awarded in the first half of 2019.

The Norwegian Government carried out extensive, detailed consultations with all 3 commercial operators – Telenor, Telia, Ice - during early 2018 to decide the best operational model for the Next Generation Nødnett (NGN). Three different solutions – Secure MVNO; single turnkey supplier; multiple turnkey suppliers – have been suggested during these consultations.[68] The main 2 mobile operators – Telenor and Telia – are close to finalising their 4G roll-outs with coverage already similar to Nødnett. Telenor is also migrating its 2G/3G networks to 4G which frees up significant spectrum in 900 MHz for further refarming opportunities. The third operator, Ice, also has a wide-area LTE network in the 450 MHz band for data communications[71].

Based on discussions with DSB, we were informed that there could be considerable costs [✂ [redacted]] to upgrade commercial networks[72] to reach public safety grade. National roaming is also under serious consideration to improve availability and reliability. Following the award of 700 MHz across Europe, if and when the guard bands (2x3 MHz and 2x5 MHz) become widely available across Europe for public safety, DSB officials believe that such frequencies could also be looked at for deployable networks, Air-To-Ground etc. The Norwegian Government[73] also paid broadcasting companies approximately €16 million to vacate the 700 MHz band on November 1st 2019 rather than in June 2021, which will accelerate the deployment of future networks.

3.3.12 Slovenia

Slovenia has deployed a nationwide TETRA network delivered by Italian equipment provider, Leonardo (formerly Selex). The win for Leonardo in 2007 was the second phase of a multi-phase deployment to create a *nationwide TETRA network for Ministry of Interior to guarantee secure and reliable communications to the Police Forces operating in in Slovenia.* The contract value was €2 million to provide coverage to over 75% of the Slovenian territory[74]. However, authorities discovered high-profile

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http://nodnett.no/globalassets/ngn/20180503-conceptual-models-for-ngn-v1.0.pdf

[69] Motorola's TEDS Solution: Enhancing Performance through Data; http://www.oppermann-telekom.de/pdf/Motorola-TEDS.pdf

[70] An English language version of the executive summary to the Study is available at: https://eng.nkom.no/technical/frequency-auctions/auctions/planned-completed-auctions/_attachment/29552?_download=true&_ts=15dcbe08c72.

[71] Overview of Ice network in Norway spectrum holdings https://halberdbastion.com/intelligence/mobile-networks/ice-norge

[72] Information in this paragraph based on interview with DSB Chief Engineer

[73] DSB (Norwegian Directorate for Civil Protection), "Next Generation Nodnett in commercial mobile networks", slide 3, TCCA CCBG, Budapest, November 14th 2018

[74] Selex wins in Slovenia, ht Reading, July 2007, https://www.lightreading.com/ethernet-ip/selex-wins-in-slovenia/d/d-id/644461

instances of security breaches in 2015[75] and at the time the network was still not completed. This, amongst other reasons have led authorities to start looking at hybrid Government-commercial (public-private partnership) solutions for next generation PPDR/public safety. Thus, Slovenia has also been leading the way in European-funded next-generation (5G) PPDR projects[76].

As a small nation surrounded by larger neighbours, Slovenia has been involved in a number of projects focused on cross-border PPDR interoperable communications, including ALPDIRIS (Alpine Disaster Relief for Italy and Slovenia) and a Horizon 2020-funded 5G PPDR Network project led by national operator, Telekom Slovenije, with the support of the regulator, AKOS[77].

Slovenia is working hard to deliver 5G to its population and emergency services as soon as possible. Discussions with commercial operators indicated, those who are successful in the 700 MHz spectrum auctions will be obliged to offer national roaming to a public safety secure MVNO with QoS, priority and pre-emption[78]. Subject to a comprehensive plan and relevant legislation, 2x3 MHz (733-736/788-791 MHz) will be set aside for PPDR, together with 2x5 MHz in 450-470 MHz. Slovenia is also one of 10 European countries (at end-2018) to have signed up for further ECC studies and a possible future decision to make 2x5 MHz available in 410-430 MHz for public services including PPDR.

3.3.13 Sweden

RAKEL is the Swedish nationwide TETRA network shared by a large number of public safety organisations. By geographical area, RAKEL is in fact the largest TETRA public safety network anywhere in the world, with roll-out completed in December 2010[79]. It is currently operated by the Swedish Civil Contingencies Agency (MSB) for all mission-critical voice and short data, with non-critical data provided through an MVNO arrangement with commercial providers.

RAKEL continues to upgrade its network with recent software upgrades to its switches[80]. Furthermore, it appears there are no published plans or dates to switch off the TETRA network, with many users still procuring TETRA handsets during early 2019[81].

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[75] Police Admit Leak Due to Fault in Crypto System in Slovenia, Critical Communications Review March 2015, http://www.criticalcommunicationsreview.com/p25/news/30385/police-admit-leak-due-to-fault-in-crypto-system-in-slovenia

[76] For example, Rudolf Susnik, Telekom Slovenije, "Slovenian 5G PPDR Initiative", 2018

[77] Slovenian 5G pilot projects, Ministry of Public Administration, www.itu.int/en/ITU-D/Reggional-Presence/Europe/Documents/Events/2018/5GHungary/S2%20Kory%20Golob.pdf

[78] Award of 700MHz, 900MHz and 2.3GHz spectrum in Denmark – spectrum for PPDR use, P14, Analysys Mason for Danish Energy Agency, Nov 2017, https://ens.dk/sites/ens.dk/files/Tele/analysys_mason_-_final_report_on_ppdr.pdf

[79] RAKEL - nationwide TETRA public safety network in Sweden, Airbus customer case. https://www.securelandcommunications.com/customerstories/rakel-nationwide-tetra-public-safety-network-in-sweden

[80] Upgrade Swedish RAKEL TETRA system 'Rolls On', Critical Communications Review, March 2018, http://www.criticalcommunicationsreview.com/p25/news/96209/upgrade-swedish-rakel-tetra-system-rolls-on

[81] Swedish Police Refresh TETRA Terminals with Sepura Devices, Mission Critical Communications, https://www.rrmediagroup.com/News/NewsDetails/NewsID/18098

During late 2016, Swedish authorities decided to postpone the 700 MHz auction[82] due to a changed security policy situation so that more time could be taken to evaluate the need for dedicated PPDR spectrum.

However, in 2017 a report for the Swedish Ministry of Justice[83] proposed an LTE-based critical communications network that will use 2 x 10 MHz FDD (703 - 713 MHz and 758 - 768 MHz) with an additional 2 x 5 MHz in the 700 MHz band (698 – 703 MHz and 753 – 758 MHz). This is proposed for the longer term once the RAKEL TETRA network is phased out and there are improvements in LTE's voice functionality for public safety. The proposal also includes the creation of and MVNO and use of a state owned evolved packet core. The report also refers to the model being similar to that of FirstNet in the US.

In February 2018, Analysys Mason conducted a cost modelling exercise for Telia Sweden[84] and found that the estimated net cost associated with deploying a dedicated BB-PPDR network could be over 2.5 times that of deploying such a network commercially. Sweden is currently considering the implementation of a dedicated and state owned PPDR network, as was recommended in the Holmgren Report.

In December 2018, Swedish regulator concluded its 700 MHz auction[85], with 2x20 MHz of the main 700 MHz band was awarded to 2 mobile operators – Telia and Net4Mobility – while the third operator, 3 Sweden, was unsuccessful and has launched a legal challenge. An extension for broadcasting services was granted for the lower part (703-713/758-768 MHz) of the band in a Ministry of Culture decision dated December 20th 2018, keeping all options open for PPDR.

Swedish operator, Net1 has upgraded its 450 MHz network in Sweden[86], Denmark and Norway (operating as Ice) from CDMA to LTE in 2015. This network is used extensively to provide services to logging companies, summer homes and other rural users, so if the 700 MHz band does not become available, capacity could easily be increased using the 400 MHz bands for public safety.

3.3.14 Switzerland

Network equipment supplier, Airbus (then, Matra Communications) and its Swiss partner, Atos, started rolling out a Tetrapol network – Polycom[87] – to public protection personnel in 2000, with a focus on providing coverage in main towns and cities and border areas with challenging terrain. In 2017, the

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[82] So much for 700MHz; Sweden scraps auction over security concerns, TelecomTV, November 2016, https://www.telecomtv.com/content/mobile/so-much-for-700mhz-sweden-scraps-auction-over-security-concerns-14085/

[83] Sweden: Report proposes hybrid network with transition to dedicated public safety RAN, Critical Communications Today, March 2017, http://www.criticalcomms.com/news/sweden-report-proposes-hybrid-network-with-transition-to-dedicated-public-safety-ran

[84] Critical communications for public protection and disaster relief - Cost and time estimates for a new Swedish PPDR network, Analysys Mason, February 2018, https://blogg.telia.se/app/uploads/sites/4/2018/03/Kostnadsanalys-Bl%C3%A5ljusn%C3%A4t.pdf

[85] Sweden's 700MHz auction raises USD312 million, Telegeography, Dec 2018, https://www.telegeography.com/products/commsupdate/articles/2018/12/11/swedens-700mhz-auction-raises-usd312-million/

[86] Alcatel-Lucent rolling out LTE-450 for Net 1 / Ice.net in Sweden, Norway, Denmark, Telegeogrpahy, Nov 2014, https://www.telegeography.com/products/commsupdate/articles/2014/11/14/alcatel-lucent-rolling-out-lte-450-for-net-1-ice-net-in-sweden-norway-denmark/

[87] For latest information on Polycom, see: www.swisscom.ch/en/business/broadcast/angebote/funkkommunikation/sicherheitsfunknetze.html

Swiss Parliament approved the budget for the modernisation of Polycom – Polycom 2030 – consisting of a full IP transmission upgrade, guaranteeing continued operations, allowing a higher number of users and increasing network capacity[88].

Tetrapol is a voice-only communications technology, so in 2014, the Swiss Government published a Request for Information (RFI) to mobile network operators to offer a mobile broadband service to emergency services personnel. 2 mobile operators – Sunrise and utility company, WZ-Systems's BLUnet and Swisscom (Public Safety Data) – have been providing separate public safety subscriptions with QoS, priority and pre-emption (QPP) over existing networks. During the annual Zurich Street Parade in August 2018, 3 public safety solutions based on LTE were tested, including a small proprietary LTE network set up by the Federal Office for Defence Procurement (Armasuisse) on behalf of the Federal Office for Civil Protection (BABS) [89].

No final model for next-generation public safety has yet been decided, although a decision is expected during 2019. An auction for spectrum suitable for the deployment of 5G in the main 700 MHz, 1.4 GHz, 3.6 GHz and 2.6 GHz bands was completed in February 2019. In the 700 MHz band, 2 x 30 MHz was awarded for commercial use. However, Switzerland is one of 10 European nations that have officially expressed an interest in the 700 MHz guard bands (2x5/2x3) with 2x3 MHz for critical IoT. The 450-470 MHz band is highly congested in major Swiss urban areas and roads, whereas 410-430 MHz is still in the early stages of standardisation for mobile broadband. Switzerland National table of frequency allocations identify the band 380-470 MHz as a tuning range for PPDR and identify PPDR (IMT as 698-703 MHz (UL) paired with 753-758 MHz (DL) and 733-736 MHz (UL) paired with 788-791 MHz (DL).[90] It further identifies that the frequency resources in the bands 698-703 MHz / 753-758 and 733-736 MHz / 788-791 MHz are foreseen for the implementation of PPDR transmitters complementary to the public mobile networks.

3.3.15 United Kingdom

In 1996, the UK Home Office was one of the first UK Government departments to select TETRA for its new, shared nationwide emergency services network setting up the PSRCP (Public Safety Radio Communications Project). The BT Airwave network was commissioned and built (2001-5) initially for the Police Service, with Ambulance, Fire and several other smaller public safety entities joining later. Changing private ownership on 3 occasions: BT to Telefonica O2 to Macquarie to Motorola Solutions (since early 2016), Airwave was at one stage the largest TETRA network in the world with over 300,000 users[91].

The UK Coalition Government set up ESMCP (Emergency Services Mobile Communications Programme) in 2011 to migrate the existing dedicated TETRA network to a shared, commercial LTE network, with the intention of saving as much as UK£300 million per year. In late 2015, the main contracts for the new Emergency Services Network (ESN) were awarded to EE (now part of BT) as network operator and Motorola Solutions as service provider. Originally scheduled to begin operations during 2016, ESN suffered a series of delays, with major reviews following during 2016 and 2018. The

[88] Airbus Press Release: "Green Light for Midlife Upgrade of Nationwide Tetrapol Network in Switzerland," March 28th, 2017

[89] For source of information for this paragraph and the next one, see 53.

[90] https://www.bakom.admin.ch/dam/bakom/de/dokumente/fp/frequenzen/nationaler_frequenzzuweisungsplan.pdf.download.pdf/nationaler_frequenzzuweisungsplan2019.pdf

[91] www.airwavesolutions.co.uk; Quixoticity: multiple articles

existing Airwave TETRA network – scheduled to be switched off in 2019 – has been extended for at least a further 3 years until 2022, with ESN switching to a multi-stage, incremental roll-out and launch starting with limited data services during 2019[92]. It should also be noted that many UK emergency services agencies have existing contracts with commercial operators for non-mission-critical data.

BT/EE has been contracted by the UK Government to deliver ESN over its existing spectrum holdings. The mobile operator has 2x5 MHz in the 800 MHz band which it is deploying to improve geographical coverage in more remote areas. It will also offer its 1800 MHz and 2.6 GHz spectrum on a priority basis to emergency services. The UK Government is also building – and will own - 292 additional sites[93] as part of an Extended Area Service (EAS) to make sure that ESN coverage is eventually comparable to existing Airwave coverage. Additional spectrum is also being considered for more specialised services such as Air-To-Ground and Device-to-Device[94].

UK regulator, Ofcom, is planning to auction 2x30 MHz in the main 700 MHz band plus an additional 20 MHz (TDD) SDL during 2019[95]. No mention has been made in the UK regarding the possibility of using the 700 MHz guard bands or Duplex gap for PPDR and 450-470 MHz is not available for the foreseeable future for PPDR use.

3.3.16 Summary

We have chosen a simple, intuitive four-colour code to highlight the different – or similar - preferences and decisions regarding Deployment Options and Spectrum Options from country to country:

- Green means that this particular option has either already been implemented, is in the process of being implemented or a clear decision has been taken by a relevant authority to implement this option.
- Orange/Amber means that such an option is being seriously considered for adoption within that particular country. A final decision might be pending or an official statement may have been made showing a preference for such an option subject to certain conditions being met.
- Yellow means that this option remains a possibility but has not yet been seriously considered. Many countries are still in the early stages of a highly complex process so they are keen to keep all options open while also closely watching pioneer countries to see which trends emerge in the future.
- Red means that an option has been rejected or that the chances of it being adopted by a particular country are extremely unlikely based on current information.

Boxes left blank indicate either that sufficient information is not available at this time to choose one of the four colours explained above or that such option is not applicable. For example, in the case of Deployment Options, those countries committed to either a dedicated or commercial strategy may have

[92] As part of research for the current document, an extensive interview was conducted with key ESN/ESMCP staff to corroborate the information contained in section 3.3.15

[93] Emergency Services Network: overview, November 2018, https://www.gov.uk/government/publications/the-emergency-services-mobile-communications-programme/emergency-services-network

[94] Cate Walton, ESMCP Technical Lead, Presentation, UK Spectrum Policy Forum Meeting, October 18th, 2018

[95] Ofcom, "Improving mobile coverage – Proposals for coverage obligations in the award of the 700 MHz spectrum band", Consultation, March 2018, https://www.ofcom.org.uk/consultations-and-statements/category-2/700-mhz-coverage-obligations

no requirements for a hybrid option. However, many countries have chosen one of the four hybrid options, making the others no longer applicable.

The 6 different Deployment Options are explained in the previous chapter of this report. Some countries may choose a national dedicated broadband network; others may look to provide PPDR applications over commercial networks, while many more have already selected or are seriously considering one of 4 hybrid options presented in this report:

- **Hybrid 1**: Geographical split between dedicated and commercial network infrastructure.
- **Hybrid 2**: Mobile Virtual Network Operator (MVNO) model where PPDR users share Radio Access Network (RAN) with the public users.
- **Hybrid 3**: MVNO model combined with a geographical split.
- **Hybrid 4**: Extended MVNO model where PPDR have dedicated carriers in the commercial network's radio transmitters/receivers throughout the country.

We show the key to what each of the colours in the table represent below.

Country	DEDICATED/HYBRID					COMMERCIAL
	Dedicated network	Hybrid 1	Hybrid 2	Hybrid 3	Hybrid 4	
Austria	Not Ruled out					Not Ruled out
Belgium	Not Ruled out		Under Consideration			Yes/Decision
Bulgaria	Under Consideration		Under Consideration			Under Consideration
Czech Republic	Not Ruled out		Not Ruled out			Yes/Decision
Denmark	Not Ruled out			Not Ruled out		Under Consideration
Finland	Under Consideration				Under Consideration	Yes/Decision
France	Under Consideration			Under Consideration		Under Consideration
Germany	Under Consideration				Under Consideration	Not Ruled out
Hungary	Under Consideration		Under Consideration	Not Ruled out		Not Ruled out
Netherlands	Not Ruled out		Under Consideration		Under Consideration	Under Consideration
Norway	No/Highly unlikely			Under Consideration		Yes/Decision
Slovenia	Under Consideration		Not Ruled out			Yes/Decision
Sweden	Under Consideration					Not Ruled out
Switzerland	Under Consideration		Under Consideration			Under Consideration
United Kingdom	No/Highly unlikely					Yes/Decision

Table 4: Summary of European Network Deployment Options

Key
Yes/Decision (green)
Under Consideration (orange)
Not Ruled out (yellow)
No/Highly unlikely (red)

The 7 different Spectrum Options are also explained in section 2.3 of this report and consider three various sized portions in the 700 MHz band, one portion in the 450 – 470 MHz band and one portion in

Country	DEDICATED/HYBRID					COMMERCIAL
	2 x 10 MHz 700 MHz Duplex	2 x 3 MHz (Band 28B)	2 x 5 MHz (Band 68)	450-470 MHz	410-430 MHz	
Austria						
Belgium						
Bulgaria						
Czech Republic						
Denmark						
Finland						
France						
Germany						
Hungary						
Netherlands						
Norway						
Slovenia						
Sweden						
Switzerland						
United Kingdom						

the 410-430 MHz band. At this stage, we have decided to remove the 700 MHz SDL option from the summary charts as we have found no evidence from any country studied in these sections of the report that PPDR is being prioritised within this band at this stage.

Table 5: Summary of European Spectrum Options

3.3.17 Conclusions

Across Europe, most Governments are now deciding – or at least studying in earnest - how to move from existing narrowband (mainly TETRA) networks to next-generation public safety/PPDR systems. The deployment and spectrum models for each of these countries – including Ireland - will be determined by a number of factors including, in particular: specific national circumstances, equipment availability, and the wider European context, being defined by CEPT/ECC spectrum decisions and the European Commission-funded and supported pan-European BroadWay framework, of which the Gardai in Ireland is a part with input from some other Irish organisations.

We have also seen that most European Governments have made significant investments in their existing narrowband networks, so it is natural for current PPDR plans to be based on the continued use of these systems until existing network support contracts come to an end or until a fully functioning broadband alternative is in place and approved by the relevant authorities.

From the 15 European countries studied, the majority are now considering how the commercial networks can form part of the solution for providing next-generation public safety/PPDR services, either on a hybrid or a standalone deployment basis. The main factors influencing such views include the capabilities of commercial networks to provide BB-PPDR services and a consideration of costs. As indicated by costing studies in a number of countries, - Denmark, Norway and Sweden - the economic costs of deploying PPDR services on a commercial network are significantly lower than the costs of building a dedicated network. However these studies also note that there are also other non-monetary considerations that need to be taken into account.

At least 4 European countries – Belgium, Czech Republic, Norway and Slovenia – have already acted to provide core PPDR services over commercial networks in the main 700 MHz band (Band 28), with many more seriously considering this approach. United Kingdom has also decided to provide public safety services over commercial networks without providing additional spectrum but with Government investment to build additional coverage sites.

At this relatively early stage in the transition process, many European nations are still considering or have not ruled out a hybrid model – at least in the medium-term – for PPDR service provision. As the country sections and charts above clearly show, a wide range of hybrid options are being considered, with relative merits very much dependent upon current social, political and financial considerations. Focusing on the main 700 MHz band, only Sweden now appears to be considering a possible future assignment of dedicated spectrum for PPDR in the main 700 MHz band, with 2x10 MHz yet to be assigned. Besides the main 700 MHz band other sub-1 GHz bands (Band 28B (2 x 3 MHz), Band 68 (2 x 5 MHz), 410 – 430 MHz and 450-470 MHz) are also potentially becoming available soon and being seriously considered for PPDR use.

From the 15 European countries studied, 9 European nations[96] – Austria, Belgium, Bulgaria, France, Germany, Netherlands, Norway, Slovenia and Switzerland have so far shown interest in using the 700 MHz guard bands for either exclusive or shared PPDR services, although France is the only country so far to have actually assigned these frequencies to public safety. Further technical studies to reduce the potential interference of TV broadcast frequencies by the lower 2x5 MHz (Band 68: 698-703/753-758 MHz) to acceptable levels are ongoing. Band 28b (2x3 MHz) is now being considered in earnest for future IoT applications of a public safety/mission-critical nature. Quantifiable demand from several European markets will be required to guarantee sufficient economies of scale and a wide range of reasonably priced equipment for future PPDR users in these bands.

Two 3GPP LTE bands – Bands 31 and 72 – are now available at 450 MHz, with networks already implemented or under consideration in Scandinavia and Eastern Europe. Existing operators, such as Ice Group, are already targeting public safety users, especially in remote areas where mobile broadband coverage is poor. However, in most Western European countries – including Ireland -, these bands are heavily congested with a wide range of incumbent narrowband users, so it is hard to imagine 2x5 MHz of clean spectrum in these bands being made available in these markets for a long time to come.

410-430 MHz is now undergoing standardisation within 3GPP. ECC decision 16(02) was amended in March 2019. This now provides three 2x5 MHz pairings in the 410-430 MHz band (410-415/420-425; 411-416/421-426, 412-417/422-427 MHz). Few countries have so far indicated that this band could be

[96] Together with Italy and Luxembourg (not studied in this report) this makes it ten European countries in total.

used for PPDR, but possible shared or exclusive spectrum is now being more openly discussed in critical communications fora.

4 Spectrum demand and options for Ireland

4.1 Introduction

In this section we assess the amount of spectrum required to support PPDR service users in Ireland. Our assessment is based on the use of the LEWP-ETSI matrix. This is a spreadsheet based spectrum requirements calculator that was used in the preparation of ECC Report 199 which is the current benchmark for PPDR spectrum needs. We have adapted this matrix to take account of the specificities of Ireland and considered which spectrum options would meet the required demand.

We further consider the spectrum options which would meet this demand, and examine the pros and cons of the various spectrum options both to the PPDR stakeholders and others who may wish to use the same spectrum.

In the later part of this section we assess the opportunity cost impact of using the main 700 MHz duplex for PPDR.

4.2 Spectrum demand assessment

The LEWP-ETSI Matrix was used extensively in the preparation of ECC Report 199 which assesses the amount of spectrum necessary to supply BB-PPDR needs. More details concerning the inputs to the matrix (i.e. the types of service included) can be found in section 2. The published version of this model produces the results found in Annex A.3.5.4 of ECC Report 199, and these results were then modified to take account of the different spectrum bands and changing scenarios for the main report content.

The functioning of the matrix can be summarised as in the diagram below.

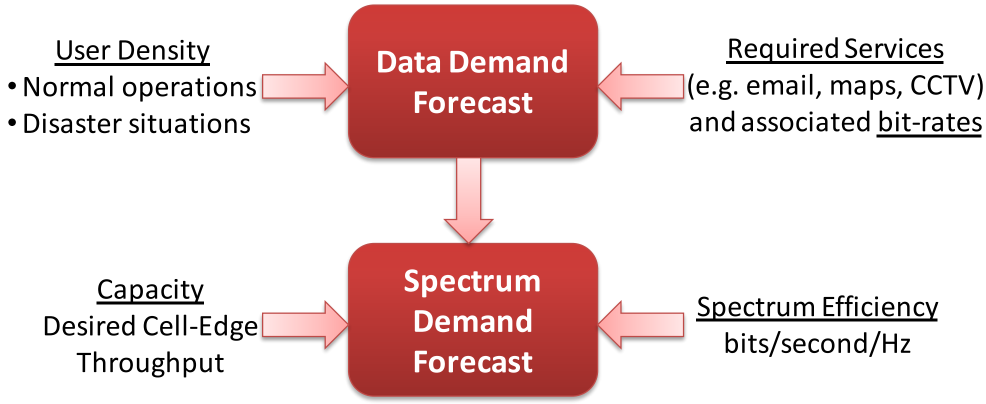

Figure 14: Summary of LEWP-ETSI spectrum demand model

The user density is taken (in users per cell) during normal, day-to-day operations, and also under stress situations such as a minor or major incident or disaster. This is a function of the number of users per square kilometre, and the number of cell sites in the same area. The current Irish TETRA network comprises 592 base station sites of which 46 are within 10 km from the centre of Dublin[97]. The number

[97] Source: Information provided by ComReg analysed by LS telcom

of users on the existing PPDR network is around 20,000[98] and we have assumed that this remains the same for any new broadband PPDR network. We have also assumed that these users and cell sites are distributed across Ireland in the same proportion as the general population, which is to say that the number of PPDR users is directly proportional to the number of population in a given area.

Area	Population (%)	PPDR users	Existing sites	Average Number of Users per site
Ireland	4,857,000[99] (100%)	20,000	592	34
Dublin City and County	1,347,000[100] (28%)	5,550	46	121
Rest of Ireland	3,510,000 (72%)	14,450	546	26

Table 6: Density of PPDR users per site

Thus the number of PPDR users in Dublin City and County would be approximately 5,550 as this represents around 28% of the total (being the ratio of the population of Dublin City and County taken to be 1,347,000 to the whole of Ireland taken to be 4,857,000). Thus in Dublin City and County there would be an average of 121 PPDR users per site. The average density of users per site across the rest of the country will be less than this at around 26.[101]

The original LEWP model which is not country specific assumes 500 users per cell for a 'normal peak' (i.e. the peak load that would occur during normal day-to-day operations), and up to 2000 users per cell for an emergency situation (i.e. where a larger number of PPDR users would congregate into a limited area). This is somewhat higher than found on average in Ireland, but the value of 500 for a normal peak in Dublin City and County seems reasonable as it assumes user density would be around 4 times higher than the simple average. The value of 2000 in an emergency, however, seems excessive.

There are a list of required services which include e-mail, map and picture download, live video and various others defined by LEWP as being important to PPDR users. Associated with each of these services (or applications) are a series of bit rates that are necessary to achieve the desired quality of the specific service, as well as an indication of the number of users who would be using the particular service at any given time (and under the different user density scenarios). As these services and applications have been developed considering a wide range of different countries, we do not believe there is a fundamental need to modify these, nor the associated bit rates or usage rates, as these are the typical services we would expect to be required in Ireland.

The cell-edge capacity is determined primarily by the density of cells and the location of users within the cells. The further away a user is from the centre of the cell, the lower the spectrum efficiency (and hence throughput) that they will experience as shown in Figure 15 below.

[98] Motorola and Tetra Ireland Consortium Deliver National Public Safety Network, https://www.motorolasolutions.com/content/dam/msi/docs/business/_documents/case_studies/_static_files/case_study_ireland_nationwide.pdf

[99] Data taken from cso.ie

[100] Data taken from dublinchamber.ie

[101] Note that if a 700 MHz network was used, additional cell sites may be needed to replicate existing coverage, meaning that the number of users per site would be somewhat lower.

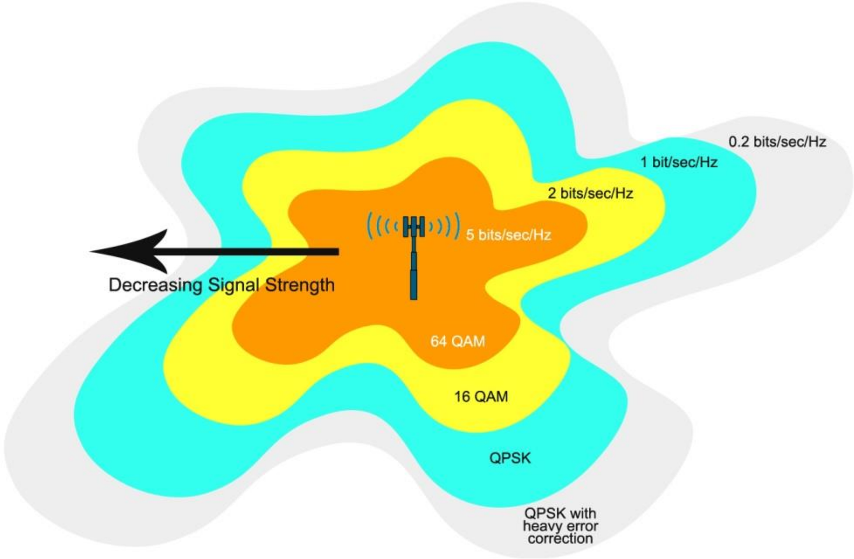

Figure 15: How spectrum efficiency decreases with distance from a cell site

If cells are closer together, the signal provided at the edge of the cell will be higher as the distance to the cell site will be smaller. If the cells are more widely spaced, the signal at the edge of the cell will be lower, as the distance is further. The lower the signal, the less effective LTE is at providing throughput which can only be counteracted by using more spectrum. Spectrum efficiency is often defined as the amount of data that can be transferred to a user within a given amount of spectrum and is measured in bits per second per Hz (bits/second/Hz). As an example, at the lowest spectrum efficiency (Channel Quality Indicator (CQI) Level 1 which is used when the signal to noise of the LTE signal is below 0dB using QPSK[102] and 1:12 error correction) is around 0.15 bits/second/Hz meaning that a 10 MHz channel will deliver a maximum of 1.5 Mbps. This can increase to over 50 Mbps in the same amount of spectrum (i.e. 5 bits per second per Hz) and same cell if the signal to noise is higher[103]. This is a fundamental factor of the technology chosen and for LTE this would therefore be the same in Ireland as elsewhere.

The spectrum efficiency of a technology is defined by the characteristics of that specific technology. TETRA, for example, has a spectrum efficiency of between 0.38 and 1.16 bits per second per Hz. As described above, LTE ranges from 0.15 to over 5 bits per second per Hz dependent upon the location of the user within a cell (and this can be further increased through the use of MIMO antennas). If it is assumed that traffic is distributed evenly across a cell then the average spectrum efficiency of an LTE system can be used to determine the amount of spectrum needed, dependent upon the amount of traffic to be carried. The table below shows the upper and lower limits of average spectrum efficiency for LTE-Advanced[104].

Up or Down link	Antenna type (MIMO)	Cell Average (bps/Hz)	Cell Edge (bps/Hz)
Uplink	1 x 2	1.2	0.4

[102] Quadrature Phase Shift Keying

[103] Source: ETSI TS 136 213 "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures"

[104] Technical Specification Group Radio Access Network. Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA)

Up or Down link	Antenna type (MIMO)	Cell Average (bps/Hz)	Cell Edge (bps/Hz)
Downlink	2 x 4	2	0.7
	2 x 2	2.4	0.7
	4 x 2	2.6	0.9
	4 x 4	3.7	1.2

Table 7: Spectrum efficiency of LTE Advanced

The LEWP model is based on the performance of LTE Release 10[105] and assumes an average uplink cell efficiency of 1 bps/Hz, and average downlink efficiency of 1.5 bps/Hz. Similarly, it assumes cell edge performance of between 0.1 and 0.3 bps/Hz for the uplink and between 0.15 and 0.3 bps/Hz for the downlink. These values seem somewhat low (they reflect the state of the art when the model was prepared) compared with the improved efficiency that LTE Advanced offers today over the LTE standard being considered at the time.

As a consequence of the above, we have re-run the model with the following alterations to the initial values:

- Emergency peak users per cell: This was initially 2000, we have reduced this to 1000 to represent the lower user density per cell expected in the Dublin City and County. For the rest of Ireland, this has been reduced to 250. In addition the 'normal peak' for the rest of Ireland has been reduced to 100 (from 500 originally).
- Average spectrum efficiency: We have increased this to be 1.2 bps/Hz in the uplink and 2.4 bps/Hz in the downlink to better reflect the state-of-the-art in LTE technology.
- Cell edge spectrum efficiency: This has also been increased to 0.4 bps/Hz in the uplink and 0.7 bps/Hz in the downlink.

The results of the original model, and the results of the adapted model are shown in the tables below. These show the amount of spectrum needed for uplink and the amount needed for downlink assuming in one instance that the downlink is unique to each user and alternatively that there is a group downlink (i.e. broadcast) function.

Scenario	Uplink (MHz)	Individual Downlink (MHz)	Group Downlink (MHz)
Peak busy hour	3.9 - 4.4	4.9	4.6 - 4.7
1 incident in a cell	7.1 - 7.5	7.8 - 8.0	5.9 - 7.2
2 incidents, one at cell edge	14.3 - 21.2	12.5 - 15.3	8.3 - 10.2

Table 8: Original results of LEWP-ETSI Matrix

Note that:

- the incident scenarios also includes the peak busy hour load;

[105] Note that this was completed in 2011 but would not have been implemented in networks for several years after this. The latest version is release 15.

- the numbers in the final line of the table (i.e. with 2 incidents) and the associated spectrum requirements were not used to define the final results in ECC Report 199 as the scenario they are meant to represent was deemed extremely unlikely to occur, but are included here for comparison purposes only.

Scenario (Dublin City and County)	Uplink (MHz)	Individual Downlink (MHz)	Group Downlink (MHz)
Peak busy hour	3.4	3.0	2.5
1 incident in a cell	6.0	4.5	2.9
2 incidents, one at cell edge	12.4	6.7	4.2

Table 9: Results of the LEWP-ETSI Matrix adapted for Dublin City and County

Scenario (The Rest of Ireland)	Uplink (MHz)	Individual Downlink (MHz)	Group Downlink (MHz)
Peak busy hour	3.4	2.9	2.5
1 incident in a cell	6.0	4.1	2.9
2 incidents, one at cell edge	12.4	5.6	4.2

Table 10: Results of the LEWP-ETSI Matrix adapted for the rest of Ireland

The results show a reduction in the amount of required downlink spectrum required for both Dublin City and County and the rest of Ireland[106]. As with the original model, the amount of spectrum required is primarily driven by uplink requirements. The results from the adapted model suggest that 2 x 6 MHz of spectrum would be sufficient for a single incident situation and that only in the case where there is an incident at the edge of the cell in addition, is this exceeded. As stated above, the scenario with 2 incidents was not used to assess final spectrum demands in ECC Report 199; the scenario with 1 incident most closely reflects the results presented in that report.

Based on these results, it is reasonable to conclude that 2 x 6 MHz would be sufficient to support PPDR usage in Ireland, both in the Dublin City and County and the rest of Ireland. It is worth noting that with LTE technology, channel bandwidths of 1.4, 3, 5 and 10 MHz are available. The requirement for 2 x 6 MHz could therefore be met by:

- 2 pieces of spectrum, each of 2 x 3 MHz in size;
- 1 piece of spectrum sized at 2 x 5 MHz, and one of 2 x 1.4 MHz (this would be slightly over the total); or
- 1 piece of spectrum sized at 2 x 10 MHz. This would be generous as it provides over 50% more capacity than the calculations suggest would be necessary.

There are other spectrum options available which all provide at least 2 x 6 MHz, and in many cases more than this. These are discussed further in the following section.

[106] Note that the amount of uplink spectrum remains the same as the services this supports require a minimum amount of spectrum to function.

4.3 Spectrum options

The various options for spectrum bands that could be used for a BB-PPDR service were discussed in section 2.3. Here we consider the situation with regards to these bands as they exist today in Ireland.

4.3.1 410 - 430 MHz

The figure below shows the current proposed usage of the frequency range 410 - 430 MHz in Ireland as being consulted upon in ComReg Document 19/23[107].

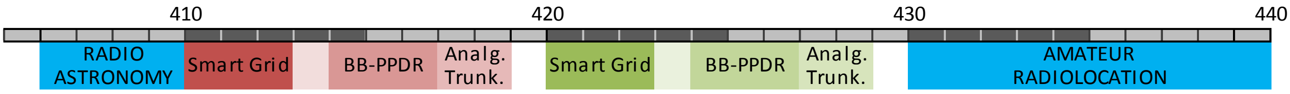

Figure 16: Proposed usage of frequency range 410 - 430 MHz in Ireland

This proposed band plan seeks to accommodate spectrum demands of both the utility/smart grid and BB-PPDR users by making 2 x 3 MHz of spectrum available for both user types. Specifically ComReg proposes that:

- 2 × 3 MHz be made available for BB-PPDR in the 414 – 417 MHz paired with 424 – 427 MHz band; and
- 2 × 3 MHz be made available for Smart Grid type applications in the 410 - 413 MHz paired with 420 - 423 MHz band. This is termed Part A in ComReg's proposed 400 MHz award.

In addition, ComReg proposes that:

- Analogue trunked services would operate in the band 417 – 418.9875 MHz paired with 427 – 428.9875 MHz band. This is to facilitate the 2 x 3 MHz allocation of spectrum for future BB-PPDR use; and
- 2 × 1 MHz be made available on a neutral basis in the 413 – 414MHz paired with 423 – 424 MHz band. This is termed Part B in ComReg's proposed 400 MHz award.

Overall, ComReg's proposal to make 2 x 3 MHz available for BB-PPDR brings the 410 – 430 MHz band into consideration for the deployment of future BB-PPDR services.

Whilst a 3GPP work item to standardise the 410 – 430 MHz band for LTE PPDR and PMR/PAMR in Europe is in progress, this frequency range is not currently a 3GPP band, and as such there is little off-the-shelf equipment currently available for the band.

However industry developments suggest that this may improve in the future depending on demand.

- Nordic Telecom, an operator in the Czech Republic, has recently indicated that it is developing a LTE network for critical communications (both emergency services communications as well as within critical industries such as energy) using the newly harmonised 410-430 MHz band[108].

[107] ComReg Document 19/23 Response to Consultation and Draft Decision on the Release of the 400 MHz Sub-band https://www.comreg.ie/publication-download/response-to-consultation-and-draft-decision-on-the-release-of-the-400-mhz-sub-band

[108] https://www.mobileeurope.co.uk/press-wire/nordic-telecom-develops-lte-network-for-critical-communications

- Nokia in its response to ComReg's 400 MHz consultation, indicates that it is already manufacturing radio head products in this band for a 3GPP FDD designation and that it is fostering a wider ecosystems with 3rd party FDD CPE/UE devices[109].
- Huawei in it response to ComReg's 400 MHz consultation indicates that it has the capability of developing both TDD and FDD products in the 410 MHz band. For the TDD product it presently intends to commercialise a system, while for the FDD product it indicates that its roadmap will depend on requests from customers[109].

Overall, given the recent CEPT harmonisation decision 16(02)[110], ongoing 3GPP standardisation, and noting industry developments, the availability of LTE equipment for this band is likely to improve in the future. However, the extent to which an ecosystem develops depends on the level of demand for LTE networks in this band, and as described in section 3.33, currently only a few countries (Hungary, Slovenia, and Czech Republic) are considering BB-PPDR in this band.

4.3.2 450 - 470 MHz

In Ireland the frequency band 450 - 470 MHz is extensively used for business radio (over 700 licences) and paging permits (almost 500 permits). The duplex pairing frequency arrangements in the band are not aligned with those that would be used for broadband services (which require a 10 MHz duplex spacing) and as such, a significant amount of re-farming would be necessary in order to clear the band of existing users to make way for a PPDR carrier, even for the smallest 2 x 1.4 MHz channel. A further challenge is the transmit and receive duplex channelling arrangements in this band which are, in some cases, reversed to that used in the 3GPP LTE broadband standard and the rest of Europe. This may further exacerbate re-farming as additional guard-bands may be necessary.

Regarding equipment availability, the 450-470 MHz is a 3GPP standardised band (Band 31) and as of March 2018, there are 115 LTE devices listed on Global mobile Suppliers Association's database.[111]

Given the current number of users and the usage of this band, re-farming the 450-470 MHz band in Ireland is likely to be a complex and costly option, as, although options exist to stop issuing licences in the band, a project of this nature would likely require considerable time to complete[112]. Users displaced would also likely require access to an alternative frequency band (or frequency arrangement in the band) to continue to provide services.

Overall, we do not consider the 450-470 MHz band to be candidate for a BB-PPDR service in Ireland at this time.

4.3.3 700 MHz

The 700 MHz band is currently used for digital terrestrial television (DTT) broadcasting, however transmitters are being migrated out of the band in order to make it available for other potential services

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[109] ComReg Document 19/23s, "Non-confidential Submissions to Document 18/92" https://www.comreg.ie/publication-download/response-to-consultation-on-the-proposed-release-of-the-400-mhz-band-non-confidential-submissions-to-document-18-92

[110] Annex 2 of new ECC Decision (19)02 specifies LTE FDD channelling arrangements for land mobile systems including the 410 – 430 MHz band.

[111] https://gsacom.com/gambod/

[112] Some licences in the band expire in 2024 and annually renewable licensees would expect a reasonable notice period.

including mobile broadband, supplemental downlink (SDL), wireless audio PMSE, Machine to Machine (M2M), and BB-PPDR services. This migration is due to be completed by March 2020[113].

There are a number of spectrum options for PPDR within this band, as were discussed in section 2.3.2. These options could provide varying amounts of spectrum for PPDR services ranging from 2 x 3 MHz to 2 x 10 MHz. These are illustrated in the figure below.

Figure 17: Frequency options for BB-PPDR in the 700 MHz band

In this band there are three (non-mutually exclusive) options:

- Option 1: 2 x 5 MHz of spectrum in frequencies immediately below the 700 MHz duplex.
- Option 2: 2 x 3 MHz of spectrum immediately above the 700 MHz duplex.
- Option 3 (not illustrated): 2 x 5 or 2 x 10 MHz of spectrum within the main 700 MHz duplex.

4.3.3.1 Option 1: 2 x 5 MHz consisting of 698-703 MHz and 753-758 MHz

Option 1 refers to 2 x 5 MHz consisting of 698-703 MHz and 753-758 MHz. Following the migration of DTT from the 700 MHz band there are a number of national options for this spectrum as set out in EC Decision (EU) 2016/687. These are wireless audio PMSE, SDL and BB-PPDR.

Considering these potential uses we note that making this band available for BB-PPDR is unlikely to adversely affect spectrum availability for the other potential uses.

- For SDL, there would be another 15 MHz of spectrum available in the 700 MHz Duplex Gap and a further 90 MHz of SDL spectrum potentially available in the 1.4 GHz band;
- For wireless audio PMSE, spectrum is available in the 470 - 694 MHz band and other bands such as 863 – 865, 1350 – 1400 and 1785 – 1804.8 MHz[114]. Further, compared to many other European countries, Ireland is likely to have a higher availability of spectrum for wireless audio PMSE in the 470 - 694 MHz given that there are only 2 DTT multiplexes in operation.

Regarding equipment availability, whilst this band has been standardised by 3GPP as a mobile band (Band 68), it is not, at present, one for which any off-the-shelf equipment is available. However we understand that one large vendor intends to support B68 (2x5 MHz) and that this vendor is also actively working with device and chipset vendors to accelerate availability of B68 user equipment (UE). The timing of equipment availability will be subject to demand.

Further, we found two examples in which Band 68 is identified as being suitable for deployment in the Arab region. In Saudi Arabia, the Saudi Telecom Company (STC) holds 2 x 5 MHz in Band 68 for PPDR and the government in the UAE was awarded 2 x 5 MHz in Band 28 and 2 x 5 MHz in lower band 68. If there is evidence of demand, it would reasonably be expected that equipment will become available to meet this demand.

As there is likely to be little interest in using this band for commercial mobile services, the availability of equipment will primarily be driven by decisions of countries to deploy PPDR networks. As discussed in

[113] ComReg 17/23 “Progress update on DTT migration to below the 700 MHz band”

[114] See ERC Recommendation 70-03

section 3, we note that one European country (France) had identified this band for PPDR, while this band is under consideration for PPDR by another four European countries (Bulgaria, Germany, Netherlands and Switzerland). Therefore, while equipment may become available in this band, it is likely that the cost of equipment (both infrastructure and user equipment) will be higher than in the 700 MHz duplex due to the economies of scale that the 700 MHz Duplex provides. This is also likely to reduce the number of vendors and range of equipment that will be available.

4.3.3.2 Option 2: 2 x 3 MHz consisting of 733-736 MHz and 788-791 MHz

Option 2 refers to 2 x 3 MHz consisting of 733-736 MHz and 788-791 MHz. As set out in EC Decision (EU) 2016/687, there are a number of potential uses for this spectrum band including wireless audio PMSE, M2M and BB-PPDR.

Making this band available for BB-PPDR is unlikely to adversely affect the spectrum availability of the other potential uses as:

- For wireless audio PMSE, spectrum is available in the 470 - 694 MHz band and various other bands as discussed above in relation to Option 1.
- For M2M or Internet of Things (IoT) services, the vast majority of these services will operate in licence-exempt spectrum. In Ireland, a large number of spectrum bands have been classified as licence-exempt bands for short-range devices[115] enabling the deployment of M2M and IOT services among others. Regarding M2M or IoT services on licensed spectrum, the majority of these services are likely to be provided by the MNOs using their existing spectrum assignments (e.g. using NB-IOT in the 800 MHz band, etc.).

Regarding equipment availability, this band is part of the Asia Pacific Telecommunity (APT) band plan for the 700 MHz band (Band 28) and there is a considerable amount of off-the-shelf equipment available. Specifically, as of March 2018, 1597 LTE devices are listed on Global mobile Suppliers Association’s database[116].

While this spectrum band represents a relatively small amount of spectrum, as discussed in section 3, a good number of European countries are considering this band for PPDR. One country (France) has already identified this band for PPDR, while another eight countries (Austria, Belgium, Bulgaria, Germany, Netherlands, Norway, Slovenia and Switzerland) are considering this band for PPDR. As it is part of a standard mobile assignment, this may also make this band particularly suitable for the provision of PPDR services on a hybrid basis using a MNOs network equipment. .

4.3.3.3 Option 3: 2 x 5 or 2 x 10 MHz in the main 700 MHz duplex (703 – 733 MHz and 758 – 788 MHz)

Option 3 comprises 2 x 5 or 2 x 10 MHz of spectrum that sits within the main duplex of the 700 MHz mobile band (3GPP Band 28). 2 x 5 MHz would need to be used in conjunction with another piece of spectrum to meet the identified 2 x 6 MHz requirement, whereas 2 x 10 MHz would fulfil (and exceed) the identified requirement.

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[115] ComReg Document 02/71r11 “Permitted Short Range Devices in Ireland” https://www.comreg.ie/publication-download/permitted-short-range-devices-ireland

[116] https://gsacom.com/gambod/

As set out in EC Decision (EU) 2016/687 the other potential use for this spectrum is wireless broadband. This is prime spectrum for commercial wireless broadband services and is regarded in Europe as a primary band for 5G services. If a block of spectrum was therefore to be made available exclusively for PPDR services this could adversely affect wireless broadband services as discussed further below.

Regarding equipment availability, as noted above for Option 2, there is a considerable amount of off-the-shelf equipment available. While this level of equipment availability and amount of spectrum makes this option attractive for the deployment of PPDR services, as discussed in section 3 above, only one country (Sweden) now appears to be considering a possible future assignment for PPDR in the band.

4.4 Opportunity cost of spectrum in the main 700 MHz duplex (Option 3)

In a situation where a dedicated PPDR network is deployed, Option 3 would be attractive for PPDR in terms of equipment availability. However, as noted above there are other viable deployment options (i.e. commercial/hybrid) and spectrum options (410-430 MHz and 700 MHz Options 1 and 2) available to support PPDR. In order to assess the opportunity cost arising from the use of the 700 MHz duplex, it is helpful to consider what uses (other than PPDR) are envisaged for the 700 MHz duplex, the benefits of those uses, and whether such uses could be provided using alternative means.

In that regard, while the band is considered important for the provision of broadband services, it has been specifically identified as an important band for:

- the delivery of 5G services (Section 4.4.2); and
- providing connectivity in rural areas[117] (Section 4.4.3)

We assess each in turn below. First, we provide a brief summary of Ireland's challenging demographics as this is relevant to the assessment that follows.

4.4.1 Ireland's challenging demographics

There are a number of challenges posed by Ireland's demographic characteristics to the deployment of infrastructure for both fixed and mobile networks. These are set out in detail in both the Oxera Report[118] and Frontier Report[119]. These are not repeated here but in summary:

- a significant proportion of the population live in rural areas;
- farmland and forestry account for 76% of the total area of Ireland;
- Ireland has an extensive road network largely located in rural areas;
- Ireland's population is not dispersed equally[120].

These factors create challenges in reaching sparsely populated areas due to the high fixed costs of laying network infrastructure and maintaining it over thinly distributed populations. Given these

[117] For 5G and more generally.

[118] ComReg 18/103c 'Future Mobile Connectivity in Ireland', Section 2.2.

[119] ComReg 18/103b 'Meeting Consumers' Connectivity Needs'

[120] For example, the urban population accounts for 67% of the population but this population is located in just 5% of the total area of Ireland. Alternatively, 37% of the rural population is spread across 95% of the area.

challenges, the use of sub-1 GHz spectrum which has propagation characteristics that benefit coverage in rural areas, the 700 MHz duplex is likely to be valuable in the delivery of 5G and rural mobile connectivity.

4.4.2 5G Services

In assessing the opportunity cost associated with allocating the 700 MHz duplex to uses (e.g. PPDR) other than wireless broadband (e.g. 5G), two main questions arise:

- What are the benefits of 5G that would be denied or reduced in the event of a different allocation?
- Is the 700 MHz band necessary to provide 5G?

We address each of the questions in turn below.

4.4.2.1 What are the benefits/objectives of providing 5G?

5G has the potential to stimulate economic growth by improving the efficiency of producing and delivering goods and services, and enabling greater innovation in the development of new products including the potential to deliver PPDR services (e.g. as a network slice). The introduction of each new generation of mobile technology has been shown to have contributed between 2% and 4% to GDP[121].

The "Towards 5G" policy of the European Commission's (EC) Digital Single Market identifies 5G as one of the most critical building blocks for the digital economy and society in the next decade[122].

A 2016 study prepared for the EC forecasting the socio-economic benefits of 5G in Europe estimates that in 2025, the benefits from the introduction of 5G capabilities could reach €113.1 billion per year and create 2.3 million jobs in Europe[123]. This EC study also estimates that the total cost of 5G deployment in EU Member States will be approximately €56.6 billion.

In relation to Ireland, this study suggests that 5G investment in Ireland will amount to around €500 million, leading to additional economic output of €1.2 billion and the creation of 10,200 jobs. The study estimates that these impacts occur across the economy with the largest impacts in telecommunication equipment, construction, wholesale, retail and transport.

In order to promote the deployment of 5G, the European Commission outlined 'pioneer bands' for 5G harmonisation in Europe in its "5G for Europe: An Action Plan"[124]. To promote the early deployment of 5G infrastructure in Europe, the 5G Action Plan has the objective of launching certain 5G services in all EU Member States by the end of 2020, followed by 5G coverage in urban areas and along main transport paths by 2025. The pioneer bands identified in the 5G Action Plan were the 700 MHz, 3.6 GHz and 26 GHz bands. We note that ComReg assigned all available spectrum in the 3.6 GHz band in 2017[125].

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[121] https://www.bcg.com/publications/2015/telecommunications-technology-industries-the-mobile-revolution.aspx

[122] https://ec.europa.eu/digital-single-market/en/towards-5g

[123] 'Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe'

[124] European Commission Communication, "5G for Europe: An Action Plan" and the accompanying "Staff Working Document", 14 September 2016

[125] https://www.comreg.ie/industry/radio-spectrum/spectrum-awards/3-6ghz-band-spectrum-award/

4.4.2.2 Is the 700 MHz band required in order to provide 5G services?

5G spectrum needs will likely encompass a range of existing and new bands, which potentially span a wide section of radio spectrum including the sub-6 GHz bands and the mmWave bands above 6 GHz. The European Commission in its mandate to CEPT notes:

> "*next-generation (5G) terrestrial wireless systems should operate both, in existing EU-harmonised frequency bands below 6 GHz and in new frequency bands above 24 GHz.*"[126]

While 5G will therefore require spectrum in high frequency bands, existing frequency bands will also be used. The 700 MHz band, being green-field spectrum, is expected to be at the forefront of providing the initial wide area coverage layer for 5G and will be used in combination with higher frequency bands (i.e. 3.6 GHz and 26 GHz) to deliver the mix of coverage and capacity necessary to meet 5G's service ambitions.

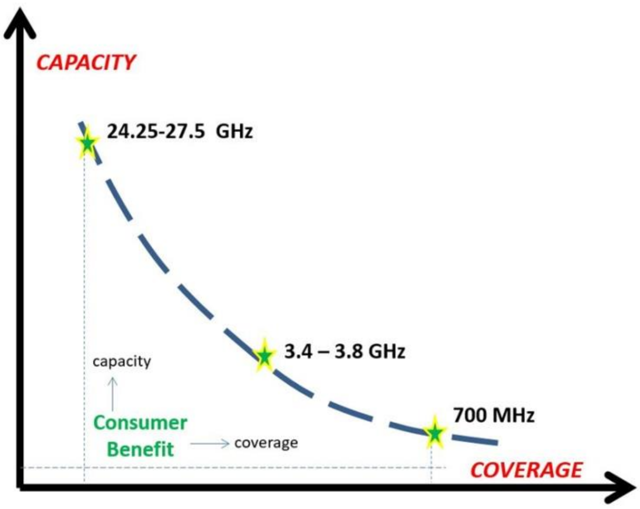

Figure 18: Different characteristics of 5G pioneer bands[127]

The RSPG expects the first major 5G commercial deployments to be in lower frequencies, in order to provide sufficient coverage for enhanced broadband communications which may require ubiquity, low latency and low complexity[128]. In that regard, the 5G Action Plan identified the 700 MHz band as being "*critical for 5G success*"[129].

The RSPG Second Opinion also noted that the Commission, together with Member States, should take actions to fully support 5G related policy objectives in rural areas and in facilitating wide area coverage. In order to provide for this, 5G deployment in the 700MHz band will be important in providing the wide area coverage necessary to support new applications (and business cases) such as, massive machine type communications (mMTC) and ultra-reliable low-latency communications (URLLC)[130]. It is worth noting that these URLLC services potentially include applications that PPDR users would be interested

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[126] Mandate to CEPT to develop harmonised technical conditions for spectrum use in support of the introduction of next-generation (5G) terrestrial wireless systems in the Union.

[127] Source: 5GPPP WG-Spectrum

[128] ibid

[129] Ibid

[130] A number of the applications (e.g. mMTC) which are not bandwidth intensive (on a per device basis) could utilise smaller blocks of spectrum.

in using. Thus the use of this spectrum for 5G services could offer additional provisions that would supplement a dedicated network, offering a hybrid solution of commercial and public networks.

5G roll-out will also eventually take place in existing bands such as 800 MHz, 1800 MHz, and 2.1 GHz. However, an operator without 700 MHz or reduced 700 MHz spectrum would likely need to re-farm other sub-1 GHz bands to support 5G services over wider areas in the nearer term. In such a scenario, operators would need to consider legacy services provided using their current spectrum holdings and plan the transition to 5G to minimise the impact on existing services. Existing bands are already used to provide 2G, 3G and 4G services, and the transition to next generation technologies will take time to ensure that existing services are not disrupted.

The RSPG refers to the likelihood of 5G networks coexisting with 4G LTE and RLAN networks in its Second Opinion noting that:

> *In due course, the mobile operators could perform transition of lower frequency mobile spectrum (800, 900, 1800, 2100, 2600 MHz) to 5G, but some studies suggest that 4G LTE and its evolutions will continue to develop in parallel to 5G deployments (as 3G continues to be used today in parallel to 4G).* [131]

This contrasts with an operator with green-field 700 MHz spectrum that does not have any legacy use to transition and who could therefore launch 5G services more quickly and with less disruption to their existing services. The RSPG[132] notes the importance of the 700 MHz band to enable 5G coverage to all areas while supporting the transition from the current to the next generation of networks.

4.4.3 Rural connectivity

Sub 1-GHz bands (including the 700 MHz band) are important for the provision of rural connectivity due to their improved wide-area propagation characteristics[133]. In assessing the opportunity cost associated with allocating the 700 MHz duplex to uses other than wireless broadband (e.g. PPDR), the same two questions arise:

- What are the benefits of rural connectivity that would be denied or reduced in the event of a different allocation?
- Is the 700 MHz band necessary to improve rural connectivity?

We address these questions in turn below.

4.4.3.1 What are the benefits/objectives of providing rural connectivity?

The importance of connectivity particularly in rural areas was highlighted in a recent report by Frontier Economics[134]. It described wider economic and societal benefits that would likely result from the assignment of the 700 MHz band, including consumer welfare benefits in the form of improved and/or

[131] RSPG Second Opinion on 5G networks (2018).

[132] ibid.

[133] There is some crossover between providing 5G in rural areas and providing connectivity more generally. However, it is helpful to assess separately as connectivity in rural areas may relate to 5G and/or other technologies.

[134] Meeting Consumers' Connectivity Needs a report from Frontier Economics

https://www.comreg.ie/publication/meeting-consumers-connectivity-needs/

lower cost services and increased demand for mobile services stimulated by greater network capacity. It also provides business connectivity in rural areas[135].

Similarly, other studies have found that access to rural broadband is important for the promotion of social inclusion, by ensuring equal access to online services and promoting the sustainability of rural communities with positive implications for the life experience of many of the most vulnerable members of Irish society, particularly the elderly[136].

The importance of the 700 MHz band in providing broadband services in rural areas has been highlighted by the Irish Government and in the EU Decision 2017/899 on the 470 - 790 MHz band, which also has set specific speed and quality of service objectives as discussed below.

Irish Government objectives

The importance of the 700 MHz Band for mobile broadband services particularly in rural areas has been highlighted by the Irish government. For example, the Irish Government previously noted that:

> *"The timely release of this spectrum is a matter of national importance to Ireland as its subsequent use for mobile broadband services will assist in delivering improved network* ***coverage and speed particularly in rural areas****."*[137] (emphasis added)

In order to facilitate clearance of the band, the government has provided compensation to RTE (as the public service multiplex operator) to cover the direct cost of migration out of the 700 MHz band. More recently, the Department of Communications, Climate Action and Environment published 'Ireland's National Roadmap on the Use of the 700MHz Frequency Band' which among other things discusses the awarding of spectrum in the 700 MHz Band for mobile phone and wireless broadband services[138].

EU Decision 2017/899 on the 470 - 790 MHz band

EU Decision 2017/899 establishes a coordinated approach across the EU to ensure the availability of wireless broadband services, while avoiding interference between such use and digital terrestrial television (DTT). In relation to rural connectivity this EU Decision notes that:

- The 700 MHz band is important for ensuring the provision of broadband services in rural areas in order to ensure access and connectivity[139].
- The 700 MHz band should allow for new innovative digital services to be developed in urban and in rural or remote areas[140].
- The 700 MHz band provides both additional capacity and universal coverage, in particular for the economically challenging rural, mountainous and insular areas as well as other remote areas,

[135] Business connectivity is also important feature of rural connectivity whose benefits include - online presence / website, communications services, remote access and machine to machine communications

[136] 'National Broadband Plan: Benefits of High Speed Broadband', PWC Report.

[137] Migration of Broadcasting Services for 700 MHz Spectrum Band - Letter of entrustment to RTE.

https://www.dccae.gov.ie/enie/communications/publications/Documents/68/Minister's%20Letter%20to%20RT%C3%89%20Chair%20setting%20out%20Act%20of%20Entrustment_Redacted.pdf

[138]https://www.dccae.gov.ie/en-ie/communications/publications/Pages/Ireland%E2%80%99s-National-Roadmap-on-the-Use-of-the-700MHz-Frequency-Band.aspx

[139] Recital 2.

[140] Recital 4.

predetermined in accordance with areas that are a national priority, including along major terrestrial transport paths[141].

Further, EU Decision 2017/899 obliges

- Member states to take due account of the need to achieve the target speed and quality objectives set out in Article 6(1) of Decision No 243/2012/EU, including coverage in predetermined national priority areas where necessary, such as along major terrestrial transport paths[142].

Overall, the above demonstrates that the 700 MHz band has been targeted as being suitable for the provision of coverage in rural areas and along major terrestrial transport paths. Any reduction in spectrum may therefore reduce the extent to which such objectives could be achieved. As noted above, these objectives are likely to be particularly relevant to Ireland which has a large rural population and challenging demographics.

4.4.3.2 Is the 700 MHz band needed to improve rural connectivity?

Spectrum in the 700 MHz band is particularly important for providing rural coverage and on major terrestrial routes[143] because it balances a number of attractive features:

- For a given power, it provides wider area coverage and better in building penetration than higher frequency spectrum; and
- Compared to higher frequency spectrum, its propagation is less affected by obstacles such as walls, trees, and weather related obstacles (such as rain and fog).

Further, in combination with other licensed bands (i.e. 800 and 900 MHz) the 700 MHz band can provide extended coverage, higher speeds and reduce network costs.

While noting the general suitability of the 700 MHz band for the provision of a wide range of services, including mobile and fixed wireless, and that both incumbents and new entrants could be interested in gaining access to the band, the assessment below draws upon the existing studies of Oxera and Frontier which were focussed on the provision of mobile services by incumbent operators.

Coverage gains

In relation to coverage, and interpreting the figures in the Oxera report:

- An operator using carrier aggregation with 10 MHz in each of the 700, 800 and 900 MHz bands would be able to achieve 30 Mbits/s of capacity at ranges of around 4.5 km from a cell-site;
- An operator using carrier aggregation with 10 MHz in each of the 800 and 900 MHz bands would be able to achieve 30 Mbits/s of capacity at ranges of up to around 3.5 km from a cell-site.

In effect, used in conjunction with the existing sub-1 GHz bands, 700 MHz provides a 65% coverage gain for speeds of 30 Mbit/s. Further, the ability to carrier aggregate the 700 MHz band with other licenced spectrum bands is an important factor in encouraging the widespread rollout of 30 Mbit/s

[141] Recital 9.

[142] Article 3(1) of Decision (EU) 2017/899 obligates Member States to work towards speed and service quality objectives set out in Article 6(1) of Decision No 243/2012/EU.

[143] Frontier Economics 'A cost benefit analysis of the change in use of the 700 MHz radio frequency band in Ireland'.

services as it reduces network costs.[144,145]

Higher speeds

Additional sub-1 GHz spectrum (e.g. 2 x 30 MHz in the 700 MHz band) makes it possible for operators to deploy extra carriers and deliver higher speeds across a wide area.

In particular and by means of example for existing mobile operators, the Oxera Report notes that from mid-2020, mobile networks are likely to switch to a focus on extending higher-speed connectivity (e.g. minimum 30 Mbit/s population coverage) partly because 700 MHz duplex rights of use become available, which will also more readily enable three-band carrier aggregation[146]. Without this, delivering 30 Mbit/s, as discussed in the Oxera report, across wide areas is more difficult to achieve, particularly in rural areas. Alternatively, according to Oxera, with 700 MHz rights of use available, population coverage of 95% of a minimum 30 Mbit/s could be achieved by 2027.

Network cost savings

For existing operators without 700 MHz spectrum, coverage, capacity and speed could be provided in rural areas by adding additional base stations to the network. However, the construction of base stations as well as extending backhaul links to new sites is expensive and often costs many multiples of the cost of adding additional spectrum to existing base stations.

In Document 15/62a[147], Frontier Economics provided a cost-benefit analysis of making the 700 MHz band available for wireless broadband services. This considered the costs of rolling out base stations in order to replicate the benefits of added capacity and performance from re-purposing the 700 MHz band. The study shows that having access to the band reduces the required number of base stations by 100 by 2025 and around 400 by 2035.

A summary of the results is set out below. This indicates total benefits of €103.5m in the base case.

Category	Base	Low	High
Network cost savings	€89 million	€50 million	€150 million
Potential performance benefits	€14.5 million	€11 million	€14.9 million
Total benefits	€103.5 million	€60 million	€165 million

Table 11: Benefits of re-purposing the 700 MHz band

Based on this study, the additional costs that would be incurred by an existing operator who did not have access to the 700 MHz band would be in the range of €20 to €55 million, with a base value of €34.5 million. To put these values in context, the Oxera Report[148] advises that mobile operators have

[144] Section 5.5.1, Oxera,'Future mobile connectivity in Ireland', Published November 2018. https://www.comreg.ie/publication/future-mobile-connectivity-in-ireland/

[145] The anticipated switch to 30 Mbit/s connectivity is also a product of the fact that the costs of providing 3 Mbit/s coverage for the last few percentage points of population rises extremely quickly. Given this, an MNO would be able to cover a significant proportion of the population with 30 Mbit/s for the same cost as expanding 3 Mbit/s.

[146] Carrier Aggregation of 2 x 10 MHz of 700 MHz spectrum, 2 x 10 MHz of 800 MHz spectrum, and 2 x 10 MHz of 900 MHz spectrum

[147] https://www.comreg.ie/publication-download/a-cost-benefit-analysis-of-the-change-inuse-of-the-700-mhz-radio-frequency-band-in-ireland

[148] ComReg 18/103c "Future Mobile Connectivity in Ireland"

annual Capex investments of €80m - €96m of which around €8m – €19m[149] is used to improve mobile coverage[150].

Providing higher speed mobile broadband services in rural areas would therefore be more expensive without the use of the 700 MHz band. If mobile operators were unable to use 700 MHz spectrum (or use a reduced amount), this would likely negatively impact the deployment of higher speed mobile services in rural areas.

Are there additional sub-1 GHz bands available?

In the USA, an additional frequency band at 600 MHz has recently been awarded[151], however, in Europe, there are no planned future sub-1 GHz bands likely to become available in the next decade. EU Decision 2017/899 obliges:

- Member States to ensure availability at least until 2030 of the 470 - 694 MHz ('sub-700 MHz') frequency band for the terrestrial provision of broadcasting services, including free television, and for use by wireless audio PMSE on the basis of national needs, while taking into account the principle of technological neutrality.[152]

In effect, there is some uncertainty about when additional green-field spectrum would become available, noting that the 600 MHz band is unlikely to become available in the foreseeable future.

4.4.4 Reduced Spectrum Outcomes

Sub 1 GHz bands are considered to be important coverage bands as the propagation characteristics mean that they provide coverage more cost-effectively than other bands and can be utilised to serve a wide geographical area.

Frequency Band	Amount of Spectrum	Typical Usage
700 MHz (to be assigned)	60 MHz (2 x 30)	Green-field (5G)
800 MHz (assigned)	60 MHz (2 x 30)	4G
900 MHz (assigned)	70 MHz (2 x 35)	2G, 3G, and 4G
Total Sub-1 GHz	**190 MHz**	

Table 12: Sub-1 GHz mobile spectrum in Ireland

As noted in Table 12, the 700 MHz band is the only 'green-field' spectrum capable of providing wide area coverage. Reducing the supply of what is an already scarce resource (i.e. available sub 1-GHz spectrum for wireless broadband) will further reduce the potential outcomes from any assignment. All service providers (e.g. mobile, fixed wireless and potential new entrants) would likely have a preference for the option that does not further reduce their ability to acquire the desired amount of spectrum. The

[149] Under a conservative estimate of only 10–20% of network investment being spent on improving mobile coverage,

[150] Future Mobile Connectivity in Ireland a report from Oxera Consulting LLP, with Real Wireless Ltd, Document 18/103c, p59.

[151] https://www.fcc.gov/600-mhz-band

[152] Article 4

following discusses the possible reduced spectrum outcomes for service providers if spectrum in the 700 MHz duplex was allocated for PPDR.

Existing mobile operators

Evidence from similar assignments in Europe indicate that there is a high level of demand for rights of use in the 700 MHz band, particularly from existing mobile operators. Mobile operators are likely to have a preference for 2 x 10 MHz of spectrum in the 700 MHz duplex.[153] Reducing the amount of 700 MHz duplex would remove the possibility of each existing mobile operator receiving 2 x 10 MHz. Reducing the amount of 700 MHz duplex for assignment would constrain supply[154] against a backdrop of excess demand for the 700 MHz duplex as (observed in awards by other administrations).

Setting aside spectrum (for potential PPDR use) would limit the options available to all three existing mobile operators. As an example, and subject to any competition cap assessment, Table 13 demonstrates the potential quantities that could be made available if PPDR is allocated 2 x 5 MHz or 2 x 10 MHz of spectrum in the 700 MHz duplex. [155]

Amount of spectrum for PPDR	Potential spectrum outcomes in the 700 MHz band		
	Outcome 1	Outcome 2	Outcome 3
2 x 5 MHz	MNO 1: 2 x 10 MHz MNO 2: 2 x 10 MHz MNO 3: 2 x 5 MHz	MNO 1: 2 x 15 MHz MNO 2: 2 x 5 MHz MNO 3: 2 x 5 MHz	MNO 1: 2 x 15 MHz MNO 2: 2 x 10 MHz MNO 3: 0 MHz
2 x 10 MHz	MNO 1: 2 x 10 MHz MNO 2: 2 x 10 MHz MNO 3: 0 MHz	MNO 1: 2 x 15 MHz MNO 2: 2 x 5 MHz MNO 3: 0 MHz	MNO 1: 2 x 5 MHz MNO 2: 2 x 5 MHz MNO 3: 2 x 10 MHz

Table 13: Reduced spectrum options for existing mobile operators with PPDR allocated 2 x 5 or 2 x 10 MHz in the 700 MHz duplex

In the case of a 3 operator market such as Ireland, any reduction in available rights of use (i.e. if some of the band is allocated to PPDR) could impact an operator's ability to compete both in terms of 5G services and/or the delivery of rural connectivity. While spectrum caps can be used to safeguard competition, a reduction in the availability of 700 MHz duplex for mobile broadband makes this more difficult given the potential post-award outcomes.

In particular, it would increase the risk of one or more operators not being assigned any 700 MHz duplex spectrum. For example, in the recent Swedish 700 MHz award, 2 x 20 MHz was made available instead of the full 2 x 30 MHz. The remaining 2 x 10 MHz block is currently reserved for DTT and its future use will be decided separately. As a result, the fourth mobile operator Hi3G (Three) did not win any 700

[153] Section 4.4.5 Oxera Report - Future mobile connectivity in Ireland.

[154] 2 x 10 MHz of spectrum represents just over 10% of all of the mobile spectrum below 1 GHz (i.e. from the 190 MHz available) and represents 33% of the 700 MHz duplex band, which, as has been discussed, is an important band for the delivery of new (e.g. 5G) services having no legacy usage.

[155] For use with 4G or 5G technologies, spectrum ideally needs to be divided into blocks which are multiples of 5 MHz wide

MHz spectrum and stated that it would appeal the 700 MHz auction results in the court[156, 157] accusing PTS[158] of poor regard for competition.

4.5 Conclusions on spectrum options

4.5.1 Conclusions on 5G and 700 MHz

In relation to 5G, we note that:

- The use of the 700 MHz band is important in order to provide for the **timely and efficient rollout of 5G** in line with the 5G Action Plan.
- There are **no alternative sub-1 GHz bands likely to become available in the next decade** that could provide near-term 5G services over wide areas. Whilst operators could re-farm existing sub-1 GHz mobile bands for 5G in due course (i.e. when equipment becomes available), the transition to 5G will take time to ensure that the existing 2G, 3G and 4G services on these bands are not disrupted.

4.5.2 Conclusion on rural connectivity

In relation to rural connectivity, we note that:

- The use of the 700 MHz band is important in order to allow operators to provide higher speed services in **rural areas and along major transport routes**.
- According to a variety of measures, Ireland has one of the most widely distributed and rural populations in Europe. Ensuring the fullest use of the **700 MHz duplex for wireless broadband services would help deliver rural connectivity** and is particularly important in Ireland.

4.5.3 Conclusions on reduced spectrum outcomes

In relation to spectrum outcomes, we note that:

- Not making the full 700 MHz duplex available may restrict one (or more) operators' ability to provide a full range of services, as a reduced assignment of the 700 MHz duplex would likely increase the network costs of providing wide-area coverage.

Given the option of making spectrum available for PPDR in the band, or dedicating the whole of the band to wireless broadband services, the assignment of 2 x 30 MHz for the provision of wireless broadband services in Ireland would appear to be the best use of the 700 MHz duplex given the availability of alternative spectrum options for PPDR.

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[156] https://www.cullen-international.com/product/documents/FLTESE20180001

157 3 Sweden plans legal challenge to 700 MHz spectrum auction result, telecompaper, December 2018, ,https://www.telecompaper.com/news/3-sweden-plans-legal-challenge-to-700-mhz-spectrum-auction-result--1272898

[158] Swedish Post and Telecom Authority

4.6 Summary and viable options

The table below summarises the equipment availability, spectrum availability and alternative use considerations for each of the PPDR spectrum options considered in this section assuming that these spectrum options are deployed for a dedicated/hybrid network. The table also provides our view of how the different portions of the 700 MHz band are impacted from a spectrum management perspective and indicates that the 410 - 430 MHz band and 700 MHz Option 2 (and to some extent Option 1) have the most potential in terms of spectrum for BB-PPDR.

Cells coloured green represent areas where there are no significant impediments. Those coloured yellow reflect a caution that some impediments may exist. Those coloured red indicate that there are significant impediments to the use of the band such that it is, to all intents and purposes, not usable for PPDR purposes.

Frequency Band	Equipment availability	Spectrum availability	Alternative uses
410 - 430 MHz (2 x 3 MHz)	Soon to be a recognised 3GPP band – work item in progress Little equipment ecosystem	2 x 3 MHz for PPDR proposed	2 x 3 MHz proposed for Smart Grid would not be affected. ComReg propose to migrate existing trunked radio licensees to facilitate the allocation of spectrum for BB-PPDR.
450 - 470 MHz	A recognised 3GPP band Some equipment available	Band not available given existing usage	Not assessed as spectrum band is unavailable in Ireland
700 MHz Option 1 (2 x 5 MHz, Band 68)	A recognised 3GPP band No equipment ecosystem yet	Band potentially available for PPDR after March 2020	Alternative users (SDL, PMSE) unlikely to be adversely impacted
700 MHz Option 2 (2 x 3 MHz, Band 28b)	A recognised 3GPP band Equipment available off-the-shelf	Band potentially available for PPDR after March 2020	Alternative users (M2M/IOT, PMSE) unlikely to be adversely impacted
700 MHz Option 3 (2 x 5 or 2 x 10 MHz, Band 28)	A recognised 3GPP band Equipment available off-the-shelf	Band potentially available for PPDR after March 2020	Significant impact for alternative use by wireless broadband.

Table 14: Summary of Spectrum Option Analysis

The spectrum demand assessment indicated a need for 2 x 6 MHz of spectrum for BB-PPDR in Ireland. There are a variety of ways in which this spectrum could be provided. The table below shows the variety of technically viable options (i.e. options with no or some impediments for equipment and spectrum availability) which would most efficiently meet this level of demand.

Note that:

- All technically viable options have been included in the following table but that many of these have impediments, in particular options D, E and F which include use of the 700 MHz duplex.
- Options D, E and F have significant number of alternative use impediments as the 700 MHz duplex band is important for future mobile broadband services in particular delivering 5G and services to Ireland's rural communities.
- Other options also exist which provide for even greater amounts of spectrum for PPDR[159], but as these would significantly exceed the calculated demand of 2 x 6 MHz, they have not been included in the table.

Option	Amount of Spectrum	410 – 430 MHz	700 MHz Option 1 (Band 68)	700 MHz Option 2 (Band 28b)	700 MHz Option 3 (Band 28)
A	2 x 6 MHz	2 x 3 MHz		2 x 3 MHz	
B	2 x 8 MHz	2 x 3 MHz	2 x 5 MHz		
C	2 x 8 MHz		2 x 5 MHz	2 x 3 MHz	
D	2 x 8 MHz	2 x 3 MHz			2 x 5 MHz
E	2 x 8 MHz			2 x 3 MHz	2 x 5 MHz
F	2 x 10 MHz				2 x 10 MHz

Table 15: Technically viable spectrum options to meet the BB-PPDR spectrum demand in Ireland

Note that Options A, B, and C, in the case of a dedicated network appear to be those which are being most closely considered by those countries examined in section 3. Given that many countries are now considering how commercial networks can form part of the solution for providing next-generation public safety/PPDR services, either on a hybrid or a standalone deployment basis, there remains some uncertainty concerning the extent to which these bands would be adopted for PPDR services. As a consequence, it is possible that the ecosystem for the 410-430 MHz band and the 700 MHz Option 1 (2 x 5 MHz, Band 68) may remain limited. This would inevitably lead to a smaller potential group of suppliers and increased equipment costs for these spectrum options.

For the 700 MHz Option 2 (2 x 3 MHz, Band 28), as this band is part of the Asia Pacific Telecommunity (APT) band plan for the 700 MHz band there is already a considerable ecosystem of off-the-shelf equipment available which will develop further over time.

Focusing on the spectrum options of 2 x 5 MHz or less, while these are unlikely to be sufficient to meet the BB-PPDR spectrum demand needs on a dedicated network basis, these spectrum options may be able to meet the PPDR spectrum demand needs when combined to form a hybrid model with a commercial service. Some of these options naturally align themselves with the different network structures.

[159] For example, combinations of the Options A, B and C would provide 2 x 11 MHz of spectrum.

For example, the use of 2 x 3 MHz in 410 – 430 MHz plus additional spectrum in the 700 MHz band would fit a hybrid or commercial structure. In the case of a hybrid model, the 410 – 430 MHz service could be operated from the existing PPDR sites, closely replicating the coverage, availability and reliability of the existing network, and the additional 700 MHz capacity could be provided through a commercial entity. Indeed, the service provided by the commercial entity need not necessarily come from dedicated PPDR spectrum, but could be as an MVNO through existing spectrum assets. This hybrid approach would give PPDR users a core of dedicated capacity, with the flexibility to use additional capacity as and where it was needed and provided by the MNO concerned.

5 Conclusions

In this section we provide a summary of the overall conclusions of the study highlighting the key findings from each of the main sections.

5.1 Wide choice of BB-PPDR network and spectrum options

There are 3 network deployment models (Dedicated, Commercial and Hybrid) for consideration in the context of BB-PPDR implementation indicating the increased flexibility and capability in network deployment. The dedicated and hybrid options require access to dedicated spectrum and the commercial options relies on the access to mobile operators existing (or future) spectrum holdings.

In terms of identification of spectrum band options, CEPT studies and recommendations have identified sufficiently sized blocks (up to 2 x 5 MHz) in two 400 MHz bands (410-430 MHz and 450 – 470 MHz) as prime candidates to support future dedicated BB-PPDR networks. In addition, four spectrum options were developed for the potential use of the European 700 MHz band plan for deploying dedicated BB-PPDR spectrum. 2 x 10 MHz has been identified as a sufficient amount of spectrum for BB-PPDR by CEPT and other organisations to support the end user applications within certain usage scenarios and expected type of deployments.

However, there are technical issues and commercial challenges to consider in practice regarding the specifics of identifying available quantities of spectrum that can be allocated for BB-PPDR use.

5.2 Move toward commercial networks and spectrum options in Europe

We studied 15 European countries, the majority of which are now considering how the commercial networks can form part of the solution for providing next-generation public safety/PPDR services, either on a hybrid or a standalone deployment basis. The main factors that are influencing such views include the increased technical capabilities of commercial networks (move to LTE) to provide BB-PPDR services and a consideration of costs, i.e. reduced capital and operational costs.

We found that the economic costs of deploying PPDR services on a commercial network are significantly lower than the costs of building a dedicated network. However these studies also note that there are also other non-monetary considerations that need to be taken into account.

At least 4 European countries – Belgium, Czech Republic, Norway and Slovenia – have already acted to provide core PPDR services over commercial networks in the main 700 MHz band (Band 28), with many more seriously considering this approach. The UK has also decided to provide public safety services over commercial networks without providing additional spectrum but with investment from Government for additional sites.

Many European nations are still considering or have not ruled out a hybrid model – at least in the medium-term – for PPDR service provision. Focusing on the main 700 MHz duplex, only Sweden now appears to be considering a possible future assignment of dedicated spectrum for PPDR, with 2x10 MHz yet to be assigned. Besides the main 700 MHz band other sub-1 GHz bands (Band 28B (2 x 3 MHz), Band 68 (2 x 5 MHz), 410 – 430 MHz and 450-470 MHz) may also become available shortly and are thus being seriously considered for PPDR use.

From the 15 European countries studied, 8 European nations[160] – Austria, Belgium, Bulgaria, France, Germany, Netherlands, Slovenia and Switzerland - have so far shown interest in using the 700 MHz guard bands for either exclusive or shared PPDR services, although France is the only country so far to have actually assigned these frequencies to public safety. While one of these 700 MHz guard bands (the 2 x 3 MHz, Band 28) is part of the Asia Pacific Telecommunity (APT) plan for the band and there is already a considerable ecosystem of off-the-shelf equipment available, for the other 700 MHz guard band (the 2 x 5 MHz, Band 68) quantifiable demand from several European or other major markets will be required to guarantee sufficient economies of scale and a wide range of reasonably priced equipment for future PPDR users.

Bands 31 and 72 (3GPP/LTE) are now available at 450 MHz, with networks already implemented or under consideration in Scandinavia and Eastern Europe. However, in most Western European countries – including Ireland - these bands are heavily congested with a wide range of incumbent narrowband users, so unlikely for 2 x 5 MHz to be available for BB-PPDR in the mid to long term.

The 410-430 MHz band is now undergoing standardisation within 3GPP. In addition, ECC decision 16(02) was amended in March 2019. This now provides three possible 2 x 5 MHz pairings in the 410-430 MHz band (410-415/420-425; 411-416/421-426 and 412-417/422-427 MHz). Few countries have so far indicated that this band could be used for PPDR, but possible shared or exclusive spectrum is now being more openly discussed in critical communications fora.

5.3 2 x 6 MHz is sufficient for BB-PPDR services in Ireland

In terms of spectrum options for BB-PPDR services in Ireland, we assume the quantity available would be needed for a dedicated or a dedicated/hybrid network. The table below shows (with green as no impediment, yellow some impediments and red significant impediments) that 410 – 430 MHz and 700 MHz option 2 (and to some extent option 1) have the most potential in terms of spectrum options for BB-PPDR.

[160] Together with Italy and Luxembourg (not studied in this report) this makes it ten European countries in total.

Frequency Band	Equipment availability	Spectrum availability	Alternative uses
410 - 430 MHz (2 x 3 MHz)	Soon to be a recognised 3GPP band – work item in progress Little equipment ecosystem	2 x 3 MHz for PPDR proposed	2 x 3 MHz proposed for Smart Grid would not be affected. ComReg propose to migrate existing trunked radio licensees to facilitate the allocation of spectrum for BB-PPDR.
450 - 470 MHz	A recognised 3GPP band Some equipment available	Band not available given existing usage	Not assessed as spectrum band is unavailable in Ireland
700 MHz Option 1 (2 x 5 MHz, Band 68)	A recognised 3GPP band No equipment ecosystem yet	Band potentially available for PPDR after March 2020	Alternative users (SDL, PMSE) unlikely to be adversely impacted
700 MHz Option 2 (2 x 3 MHz, Band 28b)	A recognised 3GPP band Equipment available off-the-shelf	Band potentially available for PPDR after March 2020	Alternative users (M2M/IOT, PMSE) unlikely to be adversely impacted
700 MHz Option 3 (2 x 5 or 2 x 10 MHz, Band 28)	A recognised 3GPP band Equipment available off-the-shelf	Band potentially available for PPDR after March 2020	Significant impact for alternative use by wireless broadband.

Table 16: Summary of Spectrum Option Analysis

Using the spectrum demand assessment which indicated a PPDR demand for 2 x 6 MHz of spectrum in Ireland, the table below shows the variety of technically viable options (i.e. the options with no or some impediments for equipment and spectrum availability) available to support this demand.

Option	Amount of Spectrum	410 – 430 MHz	700 MHz Option 1	700 MHz Option 2	700 MHz Option 3
A	2 x 6 MHz	2 x 3 MHz		2 x 3 MHz	
B	2 x 8 MHz	2 x 3 MHz	2 x 5 MHz		
C	2 x 8 MHz		2 x 5 MHz	2 x 3 MHz	
D	2 x 8 MHz	2 x 3 MHz			2 x 5 MHz
E	2 x 8 MHz			2 x 3 MHz	2 x 5 MHz
F	2 x 10 MHz				2 x 10 MHz

Table 17: Technically viable spectrum options to meet the identified requirement

Options D, E and F have significant alternative use impediments as the 700 MHz duplex band is important for future mobile broadband services and in particular delivering 5G and services to Ireland's rural communities.

Given the option of dedicating some spectrum for PPDR in the 700 MHz duplex band, or making available the whole of the band to wireless broadband services, it is the latter option (i.e. making available 2 x 30 MHz for the provision of wireless broadband services in Ireland) that would appear to be the optimal use of the 700 MHz duplex given the availability of alternative spectrum options for PPDR for the following reasons:

- The importance of 700 MHz for 5G rollout:
  - The use of the 700 MHz band is important in order to provide for the timely and efficient rollout of 5G in line with the European 5G Action Plan.
  - There are no alternative sub-1 GHz bands likely to become available in the next decade that could provide near-term 5G services over wide areas. Whilst operators could re-farm existing sub-1 GHz mobile bands for 5G, the transition to 5G will take time to ensure that the existing 2G, 3G and 4G services on these bands are not disrupted.
- The importance of 700 MHz for rural connectivity across Ireland given its challenging demographics:
  - Ireland's demographics[161] create challenges in reaching sparsely populated areas due to the high fixed costs of laying network infrastructure and maintaining it over thinly distributed populations
  - The use of the 700 MHz band is important in order to allow operators to provide higher speed services in rural areas and along major transport routes.
  - According to a variety of measures, Ireland has one of the most widely distributed and rural populations in Europe. Ensuring the fullest use of the 700 MHz duplex for wireless broadband services helps deliver rural connectivity and is particularly important in Ireland.
- Not making the full 700 MHz duplex available for wireless broadband would reduce the spectrum available for all service providers.
  - This may restrict one (or more) operators' ability to provide a full range of services, as a reduced assignment of the 700 MHz duplex would likely increase the network costs of providing wide-area coverage.

Options A, B, and C, in the case of a dedicated network, appear to be those which are being most closely considered by those countries examined in section 3. Given that many countries are now considering how commercial networks can form part of the solution for providing next-generation public safety/PPDR services, either on a hybrid or a standalone deployment basis, there remains some uncertainty concerning the extent to which these bands would be adopted for PPDR services. As a consequence, it is possible that the ecosystem for the 410-430 MHz band and the 700 MHz Option 1 (2 x 5 MHz, Band 68) may remain limited. This would inevitably lead to a smaller potential group of suppliers and increased equipment costs for these spectrum options.

[161] For example: a significant proportion of the population live in rural areas; farmland and forestry account for 76% of the total area of Ireland; Ireland has an extensive road network largely located in rural areas; Ireland's population is not dispersed equally

For the 700 MHz Option 2 (2 x 3 MHz, Band 28), as this band is part of the Asia Pacific Telecommunity (APT) band plan for the 700 MHz band there is already a considerable ecosystem of off-the-shelf equipment available which will develop further over time.

Considering the spectrum options of 2 x 5 MHz or less, while these are unlikely to be sufficient to meet the BB-PPDR spectrum demand needs on a dedicated network basis, these spectrum options may be able to meet the PPDR spectrum demand needs when combined to form a hybrid model with a commercial service.

For example, the use of 2 x 3 in 410 – 430 MHz plus additional spectrum in the 700 MHz band would fit a hybrid or commercial structure. In the case of a hybrid model, the 410 – 430 MHz service could be operated from the existing PPDR sites, closely replicating the coverage, availability and reliability of the existing network, and the additional 700 MHz capacity could be provided through a commercial entity. Indeed, the service provided by the commercial entity need not necessarily come from dedicated PPDR spectrum, but could be as an MVNO through existing spectrum assets.

6 Annex A - Reports and recommendations from CEPT/ECC

ECC Decision (08)05 (amended in June 2016) on the harmonisation of frequency bands for the implementation of digital Public Protection and Disaster Relief (PPDR) radio applications in bands within the 380-470 MHz range

ECC Decision (16)02 on harmonised technical conditions and frequency bands for the implementation of Broadband Public Protection and Disaster Relief (BB-PPDR) systems

ERC Decision (01)19 on harmonised frequency bands to be designated for the Direct Mode Operation (DMO) of the Digital Land Mobile Systems for the Emergency Services

ECC Decision (06)05 on the harmonised frequency bands to be designated for Air-Ground-Air operation (AGA) of the Digital Land Mobile Systems for the Emergency Services

ECC Decision (11)04 on Exemption from individual licensing of digital terminals of narrowband and wideband PMR/PAMR/PPDR systems and free circulation and use of digital terminals of narrowband and wideband PPDR systems operating in the 80 MHz, 160 MHz, 380-470 MHz and 800/900 MHz bands

ECC Recommendation (08)04 The identification of frequency bands for the implementation of Broad Band Disaster Relief (BBDR) radio applications in the 5 GHz frequency range

Recommendation T/R 25-08 on planning criteria and coordination of frequencies in the land mobile service in the range 29.7-470 MHz. A revision was published in September 2018. The revision includes new recommendations for the cross-border coordination of land mobile systems having different channel bandwidths on both sides of the border for the 400 MHz ranges. BB-PPDR, among others, can also be considered as a subset of "land mobile systems"

ECC Recommendation (16)03 on cross-border coordination for Broadband Public Protection and Disaster Relief (BB-PPDR) systems in the frequency band 698 to 791 MHz

ECC Report 102 on public protection and disaster relief spectrum requirements

ECC Report 110 on the compatibility studies between Broad-Band Disaster Relief (BBDR) and other systems

ECC Report 199 on user requirements and spectrum needs for future European broadband PPDR systems

ECC Recommendation (11)10 on a location tracking application for emergency and disaster situations (LAES)

ECC Report 218 on Harmonised conditions and spectrum bands for the implementation of future European Broadband Public Protection and Disaster Relief (BB-PPDR) systems

ECC Report 239 on Compatibility and sharing studies for BB PPDR systems operating in the 700 MHz range

ECC Report 240 on Compatibility and sharing studies for BB PPDR systems operating in the 400 MHz range

ECC Report 283 on Compatibility and sharing studies related to the introduction of broadband and narrowband systems in the bands 410-430 MHz and 450-470 MHz completed public consultation and was published in September 2018.

7 Annex B - Technical compatibility issues

We examine the compatibility considerations that have been addressed between PPDR and commercial mobile networks. ECC report 239[162] describes the compatibility and sharing between BB-PPDR systems operating in the 700 MHz range. The report notes there are a number of potential interference possibilities which we summarise below:

- Third order intermodulation products produced by two adjacent MFCN networks may appear in the PPDR network. This occurs when two signals at different frequencies from the MFCN base station combine to produce a third frequency (i.e. 2 x f1 - f2 = f3 which is the intermodulation product) which results in a signal in the third frequency being generated into the receiver of a device in the PPDR network. This is specific to the 700 MHz band in particular as the intermodulation product occurs within the 700 MHz duplex gap (i.e. 733 MHz – 758 MHz) when taking into account the three 2 x 10 MHz carriers in the main duplex. We show an extract of two tables from ECC Report 239 showing how a combination of each of the carriers causes the third order intermodulation products (IM3).

Table 17: Detrimental IM3 from carrier A and C

carrier A (f_{low})		carrier B		carrier C (f_{high})		$IM3_{min} = 2*f_{low}-f_{high}$	
758	768	768	778	778	788	728	758

Table 18: Detrimental IM3 from carrier A and B

carrier A (f_{low})		carrier B (f_{high})		carrier C		$IM3_{min} = 2*f_{low}-f_{high}$	
758	768	768	778	778	788	738	768

Table 19: Detrimental IM3 from carrier B and C

carrier A		carrier B (f_{low})		carrier C (f_{high})		$IM3_{min} = 2*f_{low}-f_{high}$	
758	768	768	778	778	788	748	778

Figure 19: Intermodulation products caused by 2 x 10 MHz carriers in 700 MHz band

[162] ECC Report 239 on Compatibility and sharing studies for BB PPDR systems operating in the 700 MHz range

If this intermodulation occurs the PPDR operator would need to accept this type of interference as it is challenging to mitigate against. Note that this is no different to that which would be experienced by three adjacent commercial operators.

- PPDR UL (733 – 736 MHz) and SDL; there is potential of interference from SDL towards PPDR UL if the SDL base station fulfils the out-of-block power limit[163]. It is recognised that a PPDR base station receive filter would be needed also as there is no blocking requirement for PPDR uplink receiver in the ECC Decision. Note these issues only occur if the SDL block is assigned and can be addressed by restricting the lower SDL blocks characteristics.

PPDR and DTT; interference levels from MFCN into DTT were determined in CEPT Report 53[164] which *indicates the maximum mean unwanted emission power of MFCN UE should be limited to -42 dBm/8 MHz protection of fixed DTT reception at 470 -694 MHz assuming an MFCN channel of 10 MHz or less and a 9 MHz guard band*. In ECC Report 239 the most critical interference was from PPDR UE (in the 698 – 703 MHz block) into DTT receivers in channel 48. The compatibility studies found that the existing level of -42 dBm/8MHz emission limit from a PPDR UE provides sufficient protection from interference into DTT.

[163] This is defined in ECC/DEC/(15)01

[164] CEPT Report 53 To develop harmonised technical conditions for the 694-790 MHz ('700 MHz') frequency band in the EU for the provision of wireless broadband and other uses in support of EU spectrum policy objectives, November 2014, ECC

8 Annex C - Glossary of terms

3GPP	Third Generation Partnership Project
ANPR	Automatic Number Plate Recognition
AVLS	Automatic Vehicle Location Service
BB-PPDR	Broadband-Public Protection and Disaster Relief
BEREC	Body of European Regulators for Electronic Communications
CEPT	Conference Europeen des Postes et Telecommunications
CoCo	Company Owned, Company Operated
DL	Downlink
DTT	Digital Terrestrial Television
ECC	Electronic Communications Committee
EMBB	Enhanced Mobile Broadband
E-UTRA	Evolved Universal Terrestrial Radio Access
FDD	Frequency Division Duplex
GoCo	Government Owned, Company Operated
GoGo	Government Owned, Government Operated
IOT	Internet of Things
ITU	International Telecommunications Union
LAN	Local Area Network
LEWP	Law Enforcement Working Party
LTE	Long Term Evolution
MFCN	Mobile/Fixed Communications Networks
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine Type Communications
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
PMSE	Programme Making and Special Events
PMR	Private Mobile Radio
RAN	Radio Access Network
RAS	Radio Astronomy Service
RCEG	Radiocommunication Expert Group
RSPG	Radio Spectrum Policy Group
SDL	Supplementary Downlink
SIM	Subscriber Identity Module

TCCA	TETRA and Critical Communications Association
TETRA	Terrestrial Trunked Radio
TETRAPOL	Digital professional mobile radio (open) standard, as defined by the Tetrapol Publicly Available Specification (PAS)
UHF	Ultra High Frequency (300 MHz to 3000 MHz)
UL	Uplink
ULLRC	Ultra Reliable Low Latency Communications
VPN	Virtual Private Network