PPDR-TC White Paper

The Strategic Roadmap for Next Generation (Broadband) PPDR Communication Systems

Reviewing Users Needs and Technology Evolutions towards Recommendations for Future Critical Communications policy making and technology migration

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Executive Summary

This publication discusses the solutions developed and the recommendations produced within the project PPDR-TC: Public Protection and Disaster Relief – Transformation Centre that aims to deliver the strategic roadmap for Next Generation (Broadband) PPDR communication systems. Even though the topic is quite wide and concerns a variety of stakeholders from industry, academia and governmental agencies the main audience to be targeted by this publication is policy and decision makers, at all levels, including practitioners, which will influence and subsequently shape the PPDR communication systems' environment of the future. The authors' expectations are that the discussion and the analysis herein, all of them transformed into meaningful recommendations of the future PPDR Communication Systems, shall be closely considered by policy and decision makers on the road to migration.

"PPDR services are provided by a service or agency, recognised as such by the national administrations, that provides immediate and rapid assistance in situations where there is a direct risk to life or limb, individual or public health or safety, to private or public property, or the environment but not necessarily limited to these situations" (Source: Commission Recommendation C (2003)2657).

All types of communication systems, be them narrowband, wideband or broadband, fixed or mobile, amateur or professional and terrestrial or satellite, in support of PPDR operations and services are those considered of interest in this publication. However, the main focus has been given on broadband solutions, capable on one hand of enabling enriched multimedia services of higher capacity and data speed demands, and on the other hand allowing for the majority of traditional voice applications to be inherited.

The global PPDR communication systems environment is complex and diverse and it is affected by a plethora of heterogeneous parameters. To name a few and even if the technological solutions available today are widely known, economic, political, geographical and cultural conditions pose many challenges on the "harmonisation" path. Given the different technological solutions adopted and operated across the globe, interoperability enablers could be a solution, however to fit all PPDR technologies and services seems rather unrealistic. Practitioners have expressed that interoperability, security and coverage requirements should be prioritised whilst lessons learnt from past incidents showcase the need for high service availability, reliability and resilience.

Still today, there is not a solution that fits all and legacy technologies (e.g. TETRA and TETRA 2) are expected to remain in the forefront for a while; however the promising candidates for next generation PPDR communication systems belong to the broadband realm with LTE, Wi-Fi and MANET technologies to gain ground and take the lead on the race for the most accepted PPDR communication system. Despite this success there are several matters to be resolved such as spectrum management and network deployment models that slow down full migration and give room to the existence of hybrid solutions.

As a result of this work we present and critically discuss a wide set of recommendations that encompass technical hurdles that need to be surpassed as well as decisions to be taken at higher policy levels, concerning spectrum usage, services and network deployment. All previous aspects are considered of utmost importance on the way to successful migration of the next generation PPDR communication systems.

Even if a study representing the circumstances in one specific European country would motivate the investment of a dedicated PPDR broadband network from socio-economic assessments, it is not obvious that it is the best option for PPDR agency. There are many national requirements and constraints that may result from legacy matters, best practices and future needs. A multi-dimensional analysis for such a system in an objective and balanced way, may prove to be a very difficult task to perform. It is a major concerned in each European member country that a similar study in other countries may give different results. Reasons for this could be:

- Geography - There would be significant differences in cost of providing coverage and capacity in different countries with regard to size, topography, urbanization and demography,
- Commercial alternatives - The commercial networks may differ in many ways, for example with regards to coverage, capacity and robustness. Commercial networks may have already received governmental funding to improve these areas which would also be beneficial to PPDR users,
- Different definitions of the PPDR user groups would give a different economic base for investments in dedicated PPDR networks. The definitions of PPDR user groups in each country depend, among other things, on national laws and regulations including the competition aspects,
- Funding and prioritization - In the end, it is up to each country's government to make the financial decision regarding the funding of a possible dedicated PPDR network,
- Security - It depends on national habits and regulations what security measures have to be imposed for PPDR (virtual) networks to host different PPDR agencies.

It is thus obvious that technical aspects are only one domain that has to be taken into consideration. The other are organizational and of course financial. For the latter, several business models have been already developed. They have been implemented in many countries but there are still countries that have not elaborated a consistent policy for deployment of PPDR networks that should be nationwide and can be dedicated only to some PPDR agencies or based on services leased from commercial operator(s).

Any decision makers should realize that an acquisition of PPDR networks will be never profitable whether it is based on CAPEX or OPEX. The objective is to ensure public safety for protection of citizens as well as continuous and sustainable development of the economy. For these needs to be met, efficient wireless communication networks of sufficient capacity and good quality of services have to be provided. They should also guarantee interoperability with other communication networks that are vital for crisis management.

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Table of Contents

1 Introduction

This paper reflects some of the research conclusions produced within the 30-month FP7 project PPDR-TC: Public Protection and Disaster Relief – Transformation Centre, targeting to produce the strategic roadmap towards the full migration path of future PPDR system's evolution satisfying the mid and long-term requirements for the next 10-15 years. As such, the paper mainly concerns decision makers at all different levels, ranging from **national regulators**, **standardization bodies**, **PPDR agencies** and **procurement groups** to **network operators**, **system integrators** and **technology vendors**.

In the context of this document, the authors are providing a comprehensive analysis on the following aspects: critical communications current status; existing gaps; user scenarios, services and applications; future technologies and migration barriers; architectural and business models for PPDR Networks migration; Recommendations and roadmap for technology migration.

2 PPDR Communications Ecosystem

In Europe today, the PPDR radiocommunication regime is harmonised to support narrowband digital dedicated trunked networks using a 2 x 5 MHz band between 380 and 400 MHz. These networks (mainly TETRA, TETRA 2, TETRAPOL and P25, see Figure 1) adhere to the stringent PPDR requirements for highly available and secure group voice communication whilst in parallel support a limited number of multimedia services. The network deployment and relevant infrastructure is usually built for nationwide coverage and is owned by state agencies that permit network utilisation among public protection and disaster relief (public) organisations.

As the notion of PPDR practitioners towards adoption of enriched data and multimedia services gets stronger the current narrowband infrastructure seems insufficient and Europe already demonstrates network deployments (mainly hybrid) that fill this gap. Moreover, to this direction, Conference of Postal and Telecommunications (CEPT) Electronic Communications Committee (ECC) approved ECC DEC(16)02[1] adopting the 700 MHz band as a solution to host future broadband PPDR services. It should be noted that it remains up to the national bodies to allocate such band either commercially or solely for PPDR purposes.

For example Finland and Germany have already adopted a hybrid approach to LTE in which the nationwide main PPDR network still relies on TETRA. On the other hand, France went a step beyond by allocating 2 x 3 MHz from band 28 and 2 x 5 MHz below band 28 (with plans to add 400 MHz spectrum in the future) facilitating a broadband PPDR network rollout[2]. A completely different approach is the UK case, where no dedicated spectrum for LTE deployments exists. Instead, the UK Emergency Services Network[3] will be procured and operated by a commercial mobile operator.

Across the Atlantic, in US, the harmonisation approach is also followed. The allocation included the whole band 14 in the 700 MHz spectrum, which is 2 x 10 MHz FDD band. The US Congress has authorized an independent authority, FirstNet, to build and operate nationwide public safety broadband network[4]. Although the main focus is on dedicated network with own spectrum the architecture is also supporting LTE access via partner mobile operator (hybrid). Another interesting example is South Korea that followed the US case on band 28 with plans to deploy a new nationwide LTE PPDR network operated by commercial mobile operators.

[1] Harmonised technical conditions and frequency bands for the implementation of Broadband Public Protection and Disaster Relief (BB-PPDR) systems ECC DEC(16)02 http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCDEC1602.PDF, 17 June 2016

[2] http://www.rrmediagroup.com/Features/FeaturesDetails/FID/642/

[3] https://www.gov.uk/government/publications/the-emergency-services-mobile-communications-programme/emergency-services-network

[4] http://www.firstnet.gov/news/firstnet-board-approves-release-rfp

It is evident from the above examples that the PPDR communication ecosystem is complex and diverse and harmonisation is a strongly debating subject. From such diversity it can be only assumed that the early adopters of new PPDR network schemes (mainly LTE network over different operating models or hybrid approaches of TETRA and LTE) will provide the necessary proofs on the economic and operational efficiency and effectiveness of the deployed solutions, hence drawing the path for the future (broadband) PPDR networks.

3 Defining Critical Communications

According to ITU-R, *critical communications (or PPDR communications) can be distinguished in those used by agencies and organizations responsible for dealing with maintenance of law and order, protection of life and property, and emergency situations and in those used by agencies and organizations dealing with a serious disruption of the functioning of society, posing a significant, widespread threat to human life, health, property or the environment, whether caused by accident, nature or human activity, and whether developing suddenly or as a result of complex, long-term processes*[5].

By acknowledging the above definition, this publication further presents and defines the **operational needs for critical communications** which can be organised according to the following categories:

- **Users of the application:** The users of a PPDR system are the members of all the PPDR organisations such as civil protection, fire brigades, medical services, police, security forces, etc.;
- **Typical coverage area requirements:** The coverage area of the PPDR applications analysed needs to encompass the whole geographic area of the mission, which may have the dimensions of a metropolitan area network or be even wider. The capability of using SATCOM links to provide seamless connectivity with remote locations where terrestrial infrastructure does not exist or is unavailable is also extremely valuable. In addition, indoor coverage configurations (MANETs) must also be available, especially in basements, tunnels or large and crowded environments. If different cellular communication networks are implemented, effective handover conditions must exist;
- **Required network topology:** Availability and reliability are crucial for PPDR applications, implying that the network topology must be resilient and self-organising). The ideal in terms of performance is to have an infrastructure-based network. However, if an infrastructure-less configuration is required, the existing infrastructure-base network should be capable of transforming into a full mesh architecture, in which all the nodes can be interconnected to each other and with the command and control centre;
- **Node connectivity models:** Point-to-multipoint connectivity among the devices, as well as between the devices and the CCC. This requires the establishment of downlink and uplink paths at each node for proper data flow;
- **Capacity in terms of type of data and required bandwidth:** The capacity requirements of PPDR applications vary depending on the type of data and time required for its transmission. Uplink and downlink bandwidth may vary from few to several Mbps;
- **Mobility requirements:** PPDR communication can be deployed in highly dynamic environments with a wide variety of mobility requirements;
- **Interoperability requirements:** The level of interoperation among mobile networks can be considered regarding roaming (ability of a device to roam between more than one type of network) and data exchange (exchange information using different technologies and protocols);
- **Service availability, reliability and resilience:** service availability for mission-critical applications must provide low start-up times and high level of operational availability (higher than

[5] ITU-R, Annex 15 to Working Party 5A Chairman's Report, "Public protection and disaster relief communications", 5 June 2014

99.5%). Service reliability and resilience depend on the mobile technology to be used, which must have sufficient levels of built-in redundancy;

- **Performance requirements:** PPDR communications should provide low latency and high QoS in delivering data (e.g., avoiding packet loss or prioritise voice);
- **Security:** security requirements dependent upon the nature of the data exchanged. Using frequency bands exclusive to security agencies cannot be enough to ensure security, end-to-end encryption and the use of secure device operating systems may be required. The implementation of data encryption algorithms and user authentication methods is therefore essential to comply with the security level of most PPDR applications;
- **Specific voice communication requirements:** mission-critical voice communication should consider push-to-talk (PTT), full-duplex voice systems and group call. Key elements for the definition of mission-critical voice communication are direct mode, talker identification, emergency alerting and audio quality;
- **Specific data communication requirements:** requirements capability to transmit both narrowband data (messaging), broadband data (images and video) and location-based services (asset tracking and mapping).

3.1 Today's Technology Landscape

The current **wide area mobile networks deployed by PPDR agencies in Europe** comprise a mix of analogue and digital professional mobile radio (PMR) and trunked mobile radio networks. In most countries over the last decade, the legacy analogue networks, which were prone to eavesdropping and provided little or no data capability, have been migrating to digital technologies such as TETRA and TETRAPOL. The figure below shows the current status of digital PPDR mobile networks in Europe. Note that most countries are deploying (or planning to deploy) either TETRA or TETRAPOL, the exception being Latvia which has recently decided to upgrade its PPDR communications with a Motorola ASTRO 25 system, based on the North American Project 25 (P25) standard.

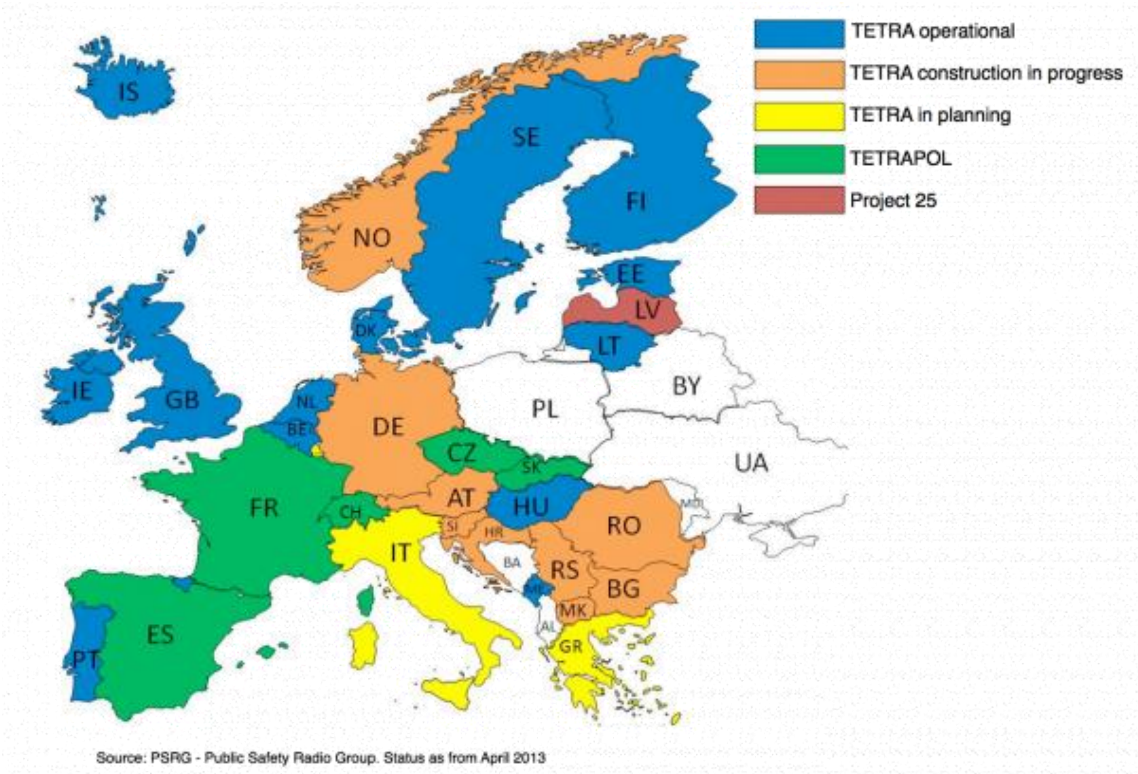

Figure 1: Current Status of digital PPDR mobile networks in Europe

Currently, PPDR wide area mobile networks in each EU country exploits in most cases the harmonized 380 – 400 MHz band, although there are some exceptions. For example, the TETRA-2 network operated in the Italian region of Emilia Romagna operates in the 450 – 470 MHz band and the RUBIS TETRAPOL network operated by the French Gendarmerie operates in the 80 MHz band. The 380 - 400 MHz band is not available in its entirety for PPDR use. Currently, only the 380-385 MHz and 390 - 395 MHz portions are available and the remainder of the band continues to be used for military purposes.

Unlike the wide area PPDR networks, which are generally well documented, there is little information on deployment of more localised **ad-hoc PPDR networks in Europe**. However, Wi-Fi is used by PPDR agencies and according to EFIS a number of EU countries have specific frequency allocations in the 5 GHz region for PPDR, which we assume relate to similar wireless LAN use.

Some European countries have already allocated spectrum on a national basis specifically for **broadband PPDR communications** or for specific applications such as video links. The most commonly used spectrum is in the 2300 – 2400 MHz range, which has also been allocated to the Mobile Service on a co-primary basis by ITU Radio Regulations in all three ITU regions[6].

In Europe specific frequencies have been identified for DMO (**Direct Mode Operation**) of TETRA, to avoid potential interference with network connections in border areas. The DMO frequencies are defined in ECC Decision (01)19 as 380-380.15 MHz and 390-390.15 MHz (twelve simplex 25 kHz channels in total). The Decision also makes provision for additional DMO frequencies to be made available on a national basis, subject to co-ordination with neighboring countries. Note that DMO does not support full duplex communication, hence only a single, unpaired frequency channel is required to set up a DMO link. Specific harmonized European frequencies have therefore been identified for A2G (**Air To Ground**) communication using the TETRA or TETRAPOL standards. These frequencies are defined in ECC Decision (01)20 as 384.8-385 MHz and 394.8-395 MHz (eight paired 25 kHz channels in total). PPDR users also sometimes deploy video links from airborne platforms. For example, in the UK the band 3442-3475 MHz is assigned to this purpose.

PPDR users also need occasional access to **satellite** frequencies for connectivity in remote areas and currently rely mainly on commercial satellite operators such as Inmarsat, although some individual agencies may deploy their own fixed satellite systems, e.g. using VSAT or transportable earth station technology.

In the US and some other parts of the world, the 800 MHz band is also used. Where broadband mobile PPDR use has been authorised or is planned, this is generally in the 700 MHz or 800 MHz range.

3.2 PPDR User Scenarios, Services and Applications

The PPDR community depends on a wide range of application and services, which need to be supported by the communications infrastructure. These applications and services deliver functionalities that allow end-users to respond more effectively and efficiently over several operational scenarios. Operational scenarios are quite dependent on the PPDR missions and may include the use of several different applications and services. In the ECC FM49 Report 199[7] eight generic operational communication scenarios are defined for PPDR users, namely:

- **Communication Scenario A:** between a central control station and field personnel at an incident location;
- **Communication Scenario B:** between PPDR vehicles and an incident location or control station;
- **Communication Scenario C:** between individuals at an incident location;
- **Communication Scenario D:** between different PPDR entities (e.g. police, fire, ambulance);

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[6] ECC Decision (14)02, Harmonised technical and regulatory conditions for the use of the band 2300 - 2400 MHz for MFCN, 27 June 2014

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

- **Communication Scenario E:** accessing information from the Internet or other external data sources (including corporate intranets);
- **Communication Scenario F:** communications in enclosed spaces (e.g., tunnels or basements);
- **Communication Scenario G:** communications with remote locations (e.g., mountains or at sea);
- **Communication Scenario H:** communications with or between machines (e.g., remotely controlled vehicles).

Furthermore, three additional variants were considered for each communication scenario, designated as operational scenarios. The operational environments set a context under which all actions undertaken in each of the communication scenarios will happen. The operational scenarios considered for the PPDR-TC project were the following:

1. **Routine operations** – Aiming to describe the aforementioned events in a routine operational context.
2. **Planned major events** – Focusing on describing the communication scenarios from the perspective of a planned event that cannot be considered as routine operations. Examples include a G7 summit, the visit of the Pope, the EU Football Champions' League final, etc.
3. **Disasters or unplanned major events** – Addressing situations that are usually associated with a crisis, such as flooding, earthquake, airplane accident, terrorist acts, upheavals, etc.

It is important to note that, due to the nature of the data available, these results do not correspond directly to functional system requirements, but rather to high-level requirements of a generic PPDR system that enables the majority of the functionalities and fulfils most of the gaps identified by the end-users questionnaires during interviews and meetings performed. Despite the requirements of a specific application may vary for distinct operational scenarios (routine operations, planned major events and disasters or unplanned major events), the applicability of that service does not depend on the operational scenario, i.e., it is constant for each communication scenario. This allowed for a significant reduction regarding the number of groups of requirements processed. The mapping between PPDR-TC communication scenarios and the applicable services (either essential or desirable) is presented on next Table 1.

The set of services that are potentially interesting for PPDR agencies and their operations were chosen based on PPDR end-user operational needs and applications. These services are presented and grouped as following:

- **Voice (common PPDR voice services)**
  - Push-to-talk
  - Private call
  - Group call
  - Emergency/priority call
  - Call retention/busy queuing
  - Direct mode operation
  - Ambience listening
  - Voice over the public switched telephone network (PSTN)
  - Area selection/dynamic group number assignment (DGNA)
- **Narrowband data (data transmission up to 384 kbps)**
  - Messaging and notifications
  - Low resolution photos
  - Automatic telemetrics
  - Location-based information
  - Mobile workspace applications
  - Access to internal databases
  - Access to external sources
- **Broadband data (data transmission above 384 kbps)**

- o Rapid file transfer
- o High resolution photos
- o Remote operations
- o Mapping with geographic information system (GIS) layers
- o Mobile workspace applications
- o Access to internal databases
- o Access to external sources
- **Video (data transmission with tighter latency and coding requirements)**
  - o Video transmission
  - o Video file transfer
  - o Video call
- **Transversal services (extension of voice and data capabilities and performance)**
  - o Extension of coverage
  - o Extension of availability
  - o Security tools
- **Challenging services (services enabled by the next generation of technologies)**
  - o Proximity services
  - o Augmented reality

Communication scenario	Application / Service																																												
	1. A(V)LS data to CCC	2. A(V)LS data return	3. Video from/to CCC for following + intervention	4. Low quality additional feeds to APP3	5. Video for fixed observation	6. Low quality additional feeds to APP5	7. Video on location to and from control room - HQ	8. Video on location to and from control room - LQ	9. Video on location for local use	10. Video conferencing operations	11. Non real time recorded video transmission	12. Photo broadcast	13. Photo to selected group	14. PDA PIMsync	15. Mobile workspace (incl. public internet)	16. Incident information download from CCC to field	17. ANPR update hit list	18. Download maps with incl. information to field	19. Comm. & control incl. task manag. + briefings	20. Incident information upload to CCC	21. Status information + location	22. ANPR/speed control automatic upload to database	23. Forward scanned documents	24. Reporting incl. pictures, etc.	25. Upload maps + schemes with incl. information	26. Patient monitoring (ECC) snapshot to hospital	27. Patient real-time monitoring (ECC) to hospital	28. Monitoring status of security worker	29. Operational data base search (own + external)	30. Remote medical database services	31. ANPR checking number plate live on demand	32. Biometric (e.g., fingerprint) check	33. Cargo data	34. Crash Recovery System (asking info. on the spot)	35. Crash Recovery (update vehicles from database)	36. Software update online	37. GIS maps updates	38. Automatic telemetrics (remote devices + sensors)	39. Hotspot on disaster or event area	40. Front-office and back-office applications	41. Alarming / paging	42. Traffic management system	43. Connectivity of abroad assigned force to local CCC	44. UAS control applications	45. Sensors on site
A: Between the CCC and PPDR personnel at the incident	✓	✓	✓	✓			✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
B: Between PPDR vehicles and the incident or the CCC	✓	✓	✓	✓			✓	✓			✓	✓	✓	✓	✓			✓	✓		✓		✓	✓					✓	✓	✓	✓	✓						✓	✓	✓				
C: Between PPDR individuals at the incident	✓	✓							✓	✓	✓	✓	✓	✓	✓			✓	✓		✓		✓	✓					✓										✓	✓	✓				
D: Between different PPDR entities	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		✓	✓	✓		✓										✓	✓	✓		✓		
E: Accessing external data sources	✓	✓	✓	✓	✓	✓						✓	✓	✓	✓	✓		✓	✓	✓	✓				✓				✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		
F: Communications in enclosed spaces	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓		✓	✓	✓	✓	✓	✓	✓		✓	✓
G: Communications with remote locations	✓	✓					✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓			✓	✓							✓	✓	✓	✓	✓		✓	✓	✓	✓
H: Communications with or between machines	✓	✓			✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓									✓	✓	✓	✓	✓		✓	✓

Table 1: Applicability of the applications to PPDR-TC communication scenarios

For the classification of all the PPDR services, a graphical and methodical tool was used. This tool allows determining whether a service can be evolved in near-, mid- or long-term by generating a spider plot composed by the three parameters:

A. The right axis represents the **MATURITY**: the external value is TRL 9 (COTS), representing a high maturity of the technologies that support the service; the inner value is TRL 1, meaning that the required technologies will only be ready in the future.

B. The left axis represents the **SCENARIOS**: the external value is 8, indicating that the service under analysis is valuable for all the scenarios presented in table 2; the inner value is 0, meaning that the service is not applicable to any scenario.
C. The top axis represents the **TIME**: the external value is 0, implying that the service should be readily available; the inner value is 15, meaning that this is still the number of years needed before the service is running in PPDR systems.

In all axes, the most external values correspond to the best cases (of near-term evolution services), while the internal ones are less ideal (representing long-term evolution services).

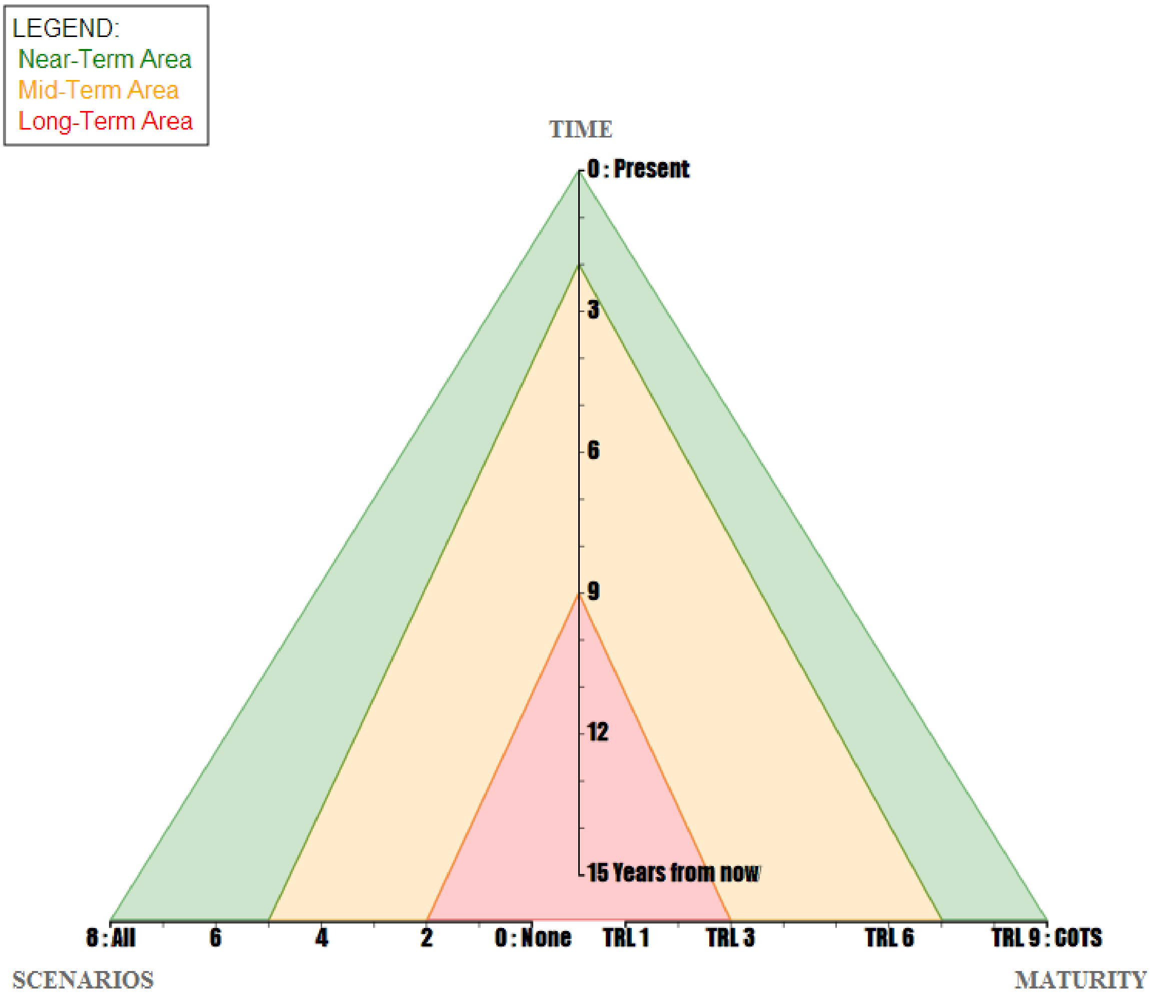

Figure 2: Outline of PPDR-TC service classification plot

Having in mind parameters such as the technological maturity, applicable scenarios and service timeframe, each service is analysed and placed in a classification scale of potential interest that ranges from near-term evolution, mid-term evolution to long-term evolution. As a result, the following Table 2 summarises the services that have been analysed and their classification in accordance with the analysis.

Service	Classification
Push-to-talk	Near-term evolution
Private call	Near-term evolution
Emergency/priority call	Near-term evolution
Call retention/busy queuing	Near-term evolution
Direct mode operation	Near-term evolution
Ambience listening	Near-term evolution
Voice over the public switched telephone network	Near-term evolution
Area selection/dynamic group number assignment	Near-term evolution

Service	Classification
Messaging and notifications	Near-term evolution
Low resolution photos	Near-term evolution
Location-based information	Near-term evolution
Extension of coverage	Near-term evolution
Extension of availability	Near-term evolution
Security tools	Near-term evolution
Group call	Mid-term evolution
Automatic telemetrics	Mid-term evolution
Mobile workspace applications (narrowband)	Mid-term evolution
Access to internal databases (narrowband)	Mid-term evolution
Access to external sources (narrowband)	Mid-term evolution
Rapid file transfer	Mid-term evolution
High resolution photos	Mid-term evolution
Mapping with geographic information system layers	Mid-term evolution
Mobile workspace applications (broadband)	Mid-term evolution
Access to internal databases (broadband)	Mid-term evolution
Access to external sources (broadband)	Mid-term evolution
Video transmission	Mid-term evolution
Video file transfer	Mid-term evolution
Video call	Mid-term evolution
Proximity services	Mid-term evolution
Augmented reality	Mid-term evolution
Remote operations	Long-term evolution

Table 2: Summary of the services classification

The main outcome of this analysis work is that the value or interest to introduce a certain communications service into a PPDR system is not solely determined by the needs and requirements manifested by potential end-users of such a service, being also constrained by:

- The **availability of mature network technologies and terminals**, able to support the service in a cost-efficient manner;
- The **applicable regulations and standards** which, among other issues, may limit the **RF spectrum** that can be allocated for the service or network.

4 Do Next Generation PPDR Communication Systems Exist Today?

Several migration barriers were identified within PPDR-TC project. These barriers are basically built upon 3 fundamental factors; the **limited radio spectrum and its currently fragmented use, the technological (in-) capability of PPDR networks**, particularly with regard to data transmission and the need for **legacy systems pay-off**.

4.1 What is keeping us back? What are the migration barriers?

Radio Spectrum

The first important barrier for migration to PPDR broadband networks is mainly the lack of spectrum harmonization and in some cases lack of spectrum resources available.

Currently the only fully harmonised dedicated PPDR spectrum in Europe is the 380 – 400 MHz band, the lower 2x5 MHz of which is used to support digital trunked radio networks, mostly based on the European TETRA standard. Specific sub-bands within this range are identified for A2G and DMO. Other bands used today on a national basis include the VHF and UHF professional mobile radio bands (80 MHz, 160

MHz and 410-470 MHz, however much of this use is expected eventually to migrate to TETRA in the 380-400 MHz band.

Spectrum has been identified by CEPT for broadband PPDR communication in the 5 GHz range, but only a few EU countries have adopted this to date, mostly in the 5150-5250 MHz band. This spectrum is shared with commercial Wi-Fi systems but PPDR users are permitted to deploy higher powers in the band, enabling significantly longer operating range. Eight EU countries are known to have existing broadband PPDR allocations in the 2 GHz, 2.3 GHz or the 3.5 GHz bands. These are typically used for terrestrial or A2G video links.

Satellite communication is sometimes used by the PPDR community, to connect to remote locations or for disaster relief operations. These generally use established generic satellite frequency bands, such as Ku-band for very small aperture terminals (VSATs) or transportable earth stations, and L-band for mobile satellite services such as Inmarsat. In the future Ka-band systems, which offer much greater bandwidth, may play an increasing role in providing backhaul or temporary communication links. There are specific bands at 406 MHz and 1.5 GHz reserved internationally for emergency satellite communications, but use of these bands is not restricted to the PPDR community. Satellite radio navigation services such as GPS also play an important role for PPDR users.

Currently most PPDR backhaul is provided by microwave links in various non-exclusive frequency bands, typically in the 450 MHz or 1400 MHz range for narrow band links and in higher bands (above 3 GHz) for broadband links.

Beyond Europe, the 800 MHz band (806-824 and 851-869 MHz) is often used, sometimes alongside spectrum in the 400 MHz range (380 - 470 MHz). In North America 2x10 MHz of spectrum has been allocated in the 700 MHz range (former TV broadcast spectrum) to broadband public safety services but the configuration of this spectrum is not compatible with other parts of the world (including Europe).

Technological constraints

PPDR **networks often become congested** under the stress characteristic of emergency events, have **limited interoperability** with other networks and have **insufficient capacity** to convey higher speed non-voice traffic. The technological gaps identified shortcomings that are applicable to all **current PPDR networks** (notably the inability of these technologies to comply with PPDR requirements for high speed data transmission), between different **public networks** (notably the lack of PPDR-specific voice communications and potential security concerns) and of **candidate networks** (also currently lacking support for PPDR-specific voice communication features).

Category	Network solution
Current PPDR technologies	TETRA Release 1
	TETRA Release 2
	TETRAPOL
	Analogue PMR
	Digital PMR
	DMR
	SATCOM
Public networks	CDMA2000
	GSM
	GPRS/EDGE
	UMTS
	HSPA/HSPA+
Candidate technologies for future PPDR applications	LTE (public/dedicated)
	Wi-Fi (public/dedicated)
	WiMAX
	MANETs

Table 3: Network solutions for PPDR communications

The technological gaps in terms of network interoperability are shown on the following two figures (Figure 3 and Figure 4), focusing on the interoperability between technologies both in terms of **roaming and data exchange**.

	TETRA 1	TETRA 2	TETRAPOL	Analogue PMR	Digital PMR	DMR	SATCOM	CDMA2000	GSM	GPRS/EDGE	UMTS	HSPA/HSPA+	LTE	Wi-Fi	WiMAX	MANETs
TETRA 1	!	!	!	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
TETRA 2	!	!	!	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
TETRAPOL	!	!	!	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Analogue PMR	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Digital PMR	✗	✗	✗	✗	!	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
DMR	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
SATCOM	✗	✗	✗	✗	✗	✗	!	✗	!	!	!	!	!	!	✗	✗
CDMA2000	✗	✗	✗	✗	✗	✗	✗	✓ (intra-handover)	✗	✗	✗	✗	✗	✗	✗	✗
GSM	✗	✗	✗	✗	✗	✗	!	✗	✓ (intra-handover)	✓	✓	✓	✓	✓	✗	✗
GPRS/EDGE	✗	✗	✗	✗	✗	✗	!	✗	✓	✓ (intra-handover)	✓	✓	✓	✓	✗	✗
UMTS	✗	✗	✗	✗	✗	✗	!	✗	✓	✓	✓ (intra-handover)	✓	✓	✓	!	✗
HSPA	✗	✗	✗	✗	✗	✗	!	✗	✓	✓	✓	✓ (intra-handover)	✓	✓	!	✗
LTE	✗	✗	✗	✗	✗	✗	!	✗	✓	✓	✓	✓	✓ (intra-handover)	✓	!	✗
Wi-Fi	✗	✗	✗	✗	✗	✗	!	✗	✓	✓	✓	✓	✓	✓	✗	✗
WiMAX	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	!	!	!	✗	!	✗
MANETs	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	!

Key: ✗ No roaming; ! Limited roaming; ✓ Good roaming; ✓ (green cell) Roaming with intra-handover

Figure 3: Roaming capabilities between technologies

	TETRA 1	TETRA 2	TETRAPOL	Analogue PMR	Digital PMR	DMR	SATCOM	CDMA2000	GSM	GPRS/EDGE	UMTS	HSPA/HSPA+	LTE	Wi-Fi	WiMAX	MANETs
TETRA 1	✓	✓	!	✗	✗	✗	!	✗	✗	!	!	!	!	!	!	!
TETRA 2	✓	✓	!	✗	✗	✗	!	✗	✗	!	!	!	!	!	!	!
TETRAPOL	!	!	✓	✗	✗	✗	!	✗	✗	!	!	!	!	!	!	!
Analogue PMR	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Digital PMR	✗	✗	✗	✗	!	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
DMR	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
SATCOM	!	!	!	✗	✗	✗	!	✗	!	!	!	!	!	!	!	!
CDMA2000	✗	✗	✗	✗	✗	✗	✗	✓	✗	!	!	!	!	!	!	!
GSM	✗	✗	✗	✗	✗	✗	!	✗	✓	!	!	!	!	✗	✗	!
GPRS/EDGE	!	!	!	✗	✗	✗	!	!	!	✓	✓	✓	✓	✓	!	!
UMTS	!	!	!	✗	✗	✗	!	!	!	✓	✓	✓	✓	✓	!	!
HSPA	!	!	!	✗	✗	✗	!	!	!	✓	✓	✓	✓	✓	!	!
LTE	!	!	!	✗	✗	✗	!	!	!	✓	✓	✓	✓	✓	!	!
Wi-Fi	!	!	!	✗	✗	✗	!	!	✗	✓	✓	✓	✓	✓	✓	!
WiMAX	!	!	!	✗	✗	✗	!	!	✗	!	!	!	!	✓	✓	!
MANETs	!	!	!	✗	✗	✗	!	!	!	!	!	!	!	!	!	!

Key: ✗ No data exchange; ! Limited data exchange; ✓ Good data exchange

Figure 4: Data exchange capabilities between technologies

Old Investments pay-off

Existing narrowband networks will be still operated due to their maturity. TETRA networks will have been operating for long time yet as the most safety and reliable system for voice communication because its Critical Communication advantages have been already proven. For example, German BOSNet network based on TETRA standard was planned to have been fully deployed by 2015. TETRA networks will be also built by energy sector's companies in Poland. TETRAPOL networks are used by PPDR organizations in France and Spain. In Czech the energy sector built a digital network based on DMR standard.

In many countries these networks have not been paid off yet. The capital expenditures bore many years ago to build national-wide wireless networks were rather huge because the technology was new that time. It constitutes a mental decision against investments in a new network even if it is to be broadband because it is rather difficult to convince decision-makers to lay out money once more. Such a new network can of course provide broadband services. Due to them processes used by PPDR entities can be managed more efficient and with better level of quality in order to improve operations taken by PPDR forces. However in many opinions the expected enhancements are not so great to justify the expenditures that can be even greater than in a case of narrowband networks due to bands of higher frequencies that are going to be used to have radio channels of wide bandwidth.

Above confusion has come to the conclusion that new business models for acquisition of broadband networks are needed in order to find a trade-off between expenditures and advantages that can be attributed to new transmission solutions with the broadband access layer. The final decision about selection of a more efficient business model can be taken in few years because a new release of LTE standard that meets PPDR requirements is expected to have been approved by 2019.

That is why many legacy systems do well due to few reasons:

- voice communication remains the most important service to communicate,
- systems used are mature,
- networks have enough capacity,
- high level of security and safety is met,
- operating expenditures are reduced because only new terminal are bought and batteries are replaced,
- any broadband needs can be easily achieved using public 3G/4G networks.

Moreover many narrowband systems (e.g. TETRA, DMR and dPMR) are still developed to provide new services. They have become IP-centric systems with all-IP backhaul and core networks. They can even provide IP packet data transmission. These transmission features are available for moderate prices because older technologies became more widespread due to increased competition.

5 How the Future Mission Critical Communication Systems look like?

5.1 Dominant technologies

During the PPDR research project many technologies were discussed and various aspects noted, throughout this process the following technologies were the most dominant and the results of this analysis are briefly discussed within this chapter.

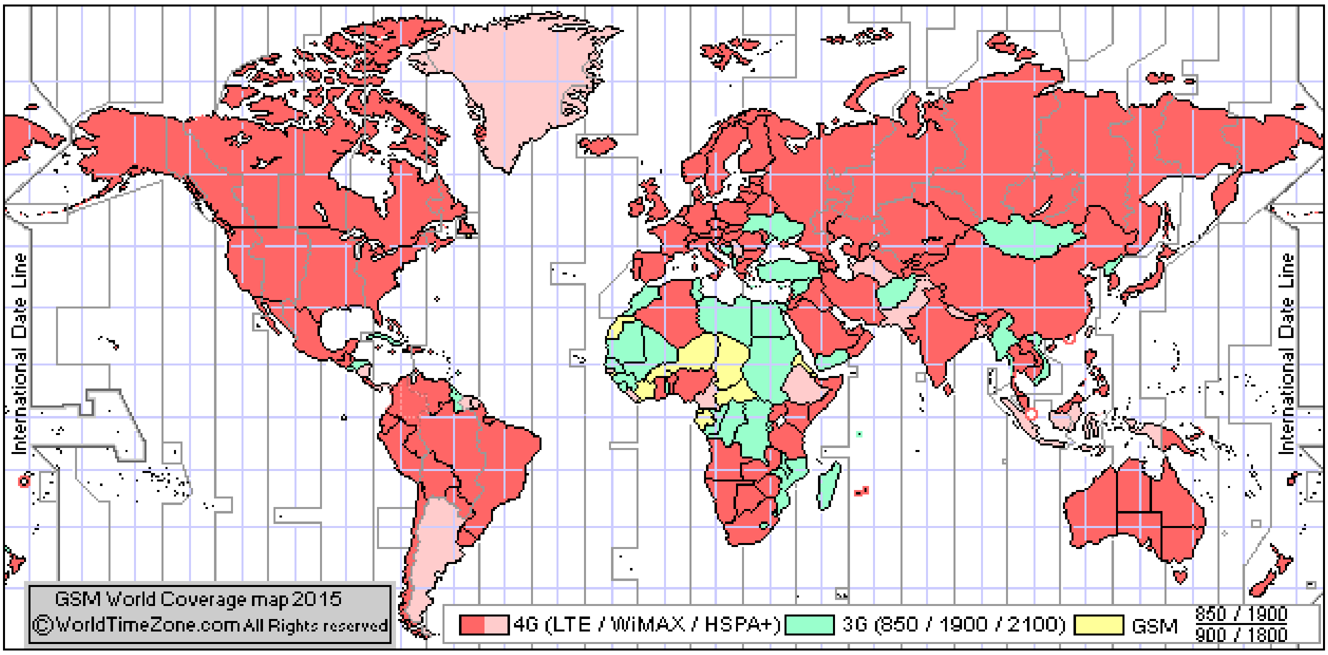

Figure 5: LTE deployment over the world[8]

LTE - By far the most promising technology, not only from a technological point of view but also from a business point of view as it is currently being adopted by several public communication provider companies. This potentiates the option for the PPDR communities to lease a publicly operated LTE infra-structure, instead of managing their own private infra-structure. This option may not be as easily found for other technologies (e.g. WiMAX). With widespread adoption across the EU (see figure below), LTE is the most promising technology for PPDR communications for short and mid-term deployment as it is able to provide specific public safety requirements and supports a high data rate, low latency network[8].

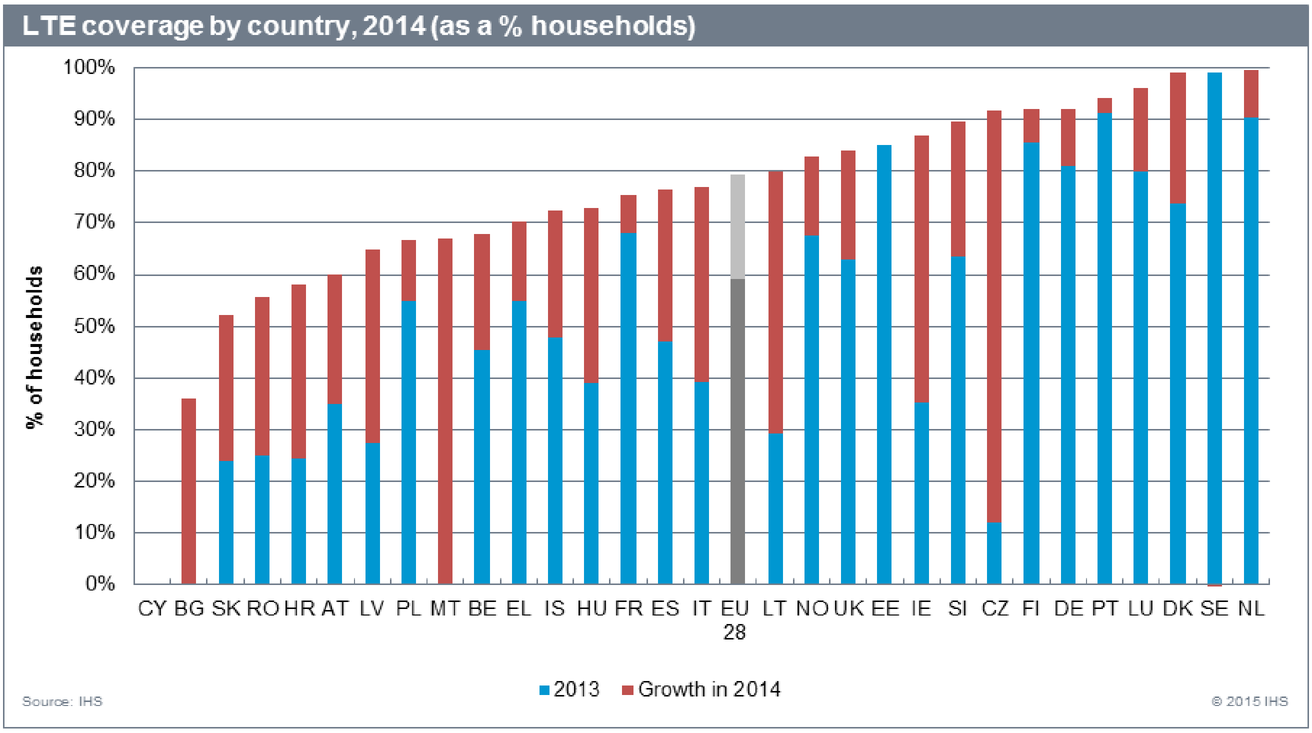

Figure 6: LTE coverage by country, 2014[9]

[8] http://www.ppdr-tc.eu/en/index.php?about=39

In the short term LTE is expected to support broadband data services solely, in the mid-term (10 years from now) it is expected that LTE will allow for a higher level of interoperability with TETRA technology which will be phased out over the longer term. From the longer term (15 to 20 years) it is expected that LTE will then support mission critical capabilities as a mature technology and will replace TETRA as the core PPDR network infrastructure.

Wi-Fi (public/dedicated) – Offers a robust and popular protocol which is ubiquitous amongst many devices such as smartphones/laptops and others. Allows creation of a wireless communication network for local users, this is a matured technology which is dominant for local network infrastructure - e.g. within operational areas. With high connection speeds (up to 150Mbps for the 802.11n standard) Wi-Fi offers a cost effective network for use at local incident sites such as those explored within the PPDR project (planned and unplanned events). With a limited range it can only offer localized network and relies on a back-haul network (such as LTE) for longer distance communication.

MANETs – Although niche, MANETs technology offers a feasible method to allow network connectivity in areas where terrestrial networks fail – underground, in difficult terrain – caves/tunnels etc. Currently networks such as LTE and TETRA are unable to provide adequate coverage in such areas and during an incident the use of a MANET is highly beneficial to allow for a usable communications network where it would not otherwise be possible without existing emergency infrastructure in place. Data rates of representative technologies[10] investigated during the PPDR project offered up to 50 Mbps which is shown to be sufficient for transmission of multiple video streams or for multiple VoIP conversations along with background data. Thus MANETs may provide enhanced network coverage in planned events or unplanned events whereby terrestrial networks are unavailable or compromised.

This section covered the technologies determined by the PPDR project as the most dominant and likely to be deployed by PPDR agencies in the short, middle and long term. With widespread market adoption only LTE stood out as the core technology able to offer the coverage required for day to day events where Wi-Fi and MANETs offer only a support role to LTE and legacy TETRA systems.

5.2 Architectural Models

In this section we highlight the main architectural models devised during the PPDR-TC project with a particular emphasis regarding the architectures which involve the technologies described in the previous section.

5.2.1 Shared Radio Access Network

Broadband RAN is deployed managed by a CMNO who shares it with PPDR agency. A PPDR organization owns the core network. Such a 3G/LTE network is used for voice and data. However, mission-critical voice remains in the currently PMR network. This option is a mix of:

- Sub-model 3.2 presented in D4.1. PPDR entities build a dedicated core and service node. This sub-model enables the PPDR operator to have full control of the PPDR users with respect to their subscriptions, service profiles and service offerings;
- Scenario 4 (described in http://www.3gpp.org/DynaReport/22803.htm) where a new broadband network is a hybrid scenario combining existing PPDR networks with a phased move to a common LTE mix of dedicated and commercial. However, in this Option 3 in D3.3 only commercial LTE network is used.

The network architecture is shown in Figure 7. There are three sub-networks:

- 3G one operated by MNO,

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[9] Dramatic Rise in European 4G Coverage and High-Speed Broadband, IHS and European Commission Study, June 19, 2015, http://press.ihs.com/press-release/technology/dramatic-rise-european-4g-coverage-and-high-speed-broadband-ihs-and-europea

[10] http://www.rinicom.com/products/cofdm-ip-mesh-radios/podnode-cofdm-ip-mesh-technology/

- 4G one operated by MNO,
- TETRA/TETRAPOL one operated by PPDR agency that plays a role of operator.

There are also a few components operated by MVNO that are needed to virtualize network resources. MVNO is the PPDR agency or an operator delegated by PPDR agency. As compared to the model of SP MVNO, there are much more commitments in this model that have to be met the operator.

MNO's 3G network consists of (a) RAN that composes of Node-B, and RNC, and (b) core network where the most important components are the SGSN, and the Gateway Mobile Switching Centre (GMSC). MVNO's 3G core network is composed of (a) Circuit Switching (CS) consisting of Mobile Switching Centre (MSC), Visited Location Register (VLR), Equipment Identity Register (EIR), and GMSC, as well as (b) Packet Switching (PS) with GGSN. In 3G CS domain MVNO operates the CS Gateway (CS GW). Common components for 3G CS and PS domains in the MVNO network are HLR, Short Messaging Service Centre (SMS-C), Multimedia Message Service Centre (MMS-C), and Value-Added Service platform.

MNO's 4G network consists of (a) RAN that composes of eNB and (b) core network where the most important components are MME and S-GW. MVNO's 4G core network is composed of S-GW, P-GW, HSS, AAA, SPR, IMS Core, AS.

Moreover there are some common elements for 3G and 4G sub-networks operated by MNO, namely the backhaul network, the backbone network and the Operation and Maintenance Centre (OMC).

At the MVNO site there are also some common elements for 3G and 4G sub-networks like LI, OMC, CCBS, and PS GW used by 3G PS domain and 4G.

MVNO who is a PPDR agency-operator governs the 3G CS and PS core, the service platforms, the 3G CS and 3G/4G PS gateways, the 4G core, the provision of services using IMS Core and AS, and the customer care system that allows managing PPDR entities' customers.

In TETRA/TETRAPOL sub-network there are:

- Base Stations (BS),
- Switching Centre,
- interoperability Gateway (GW),
- OMC.

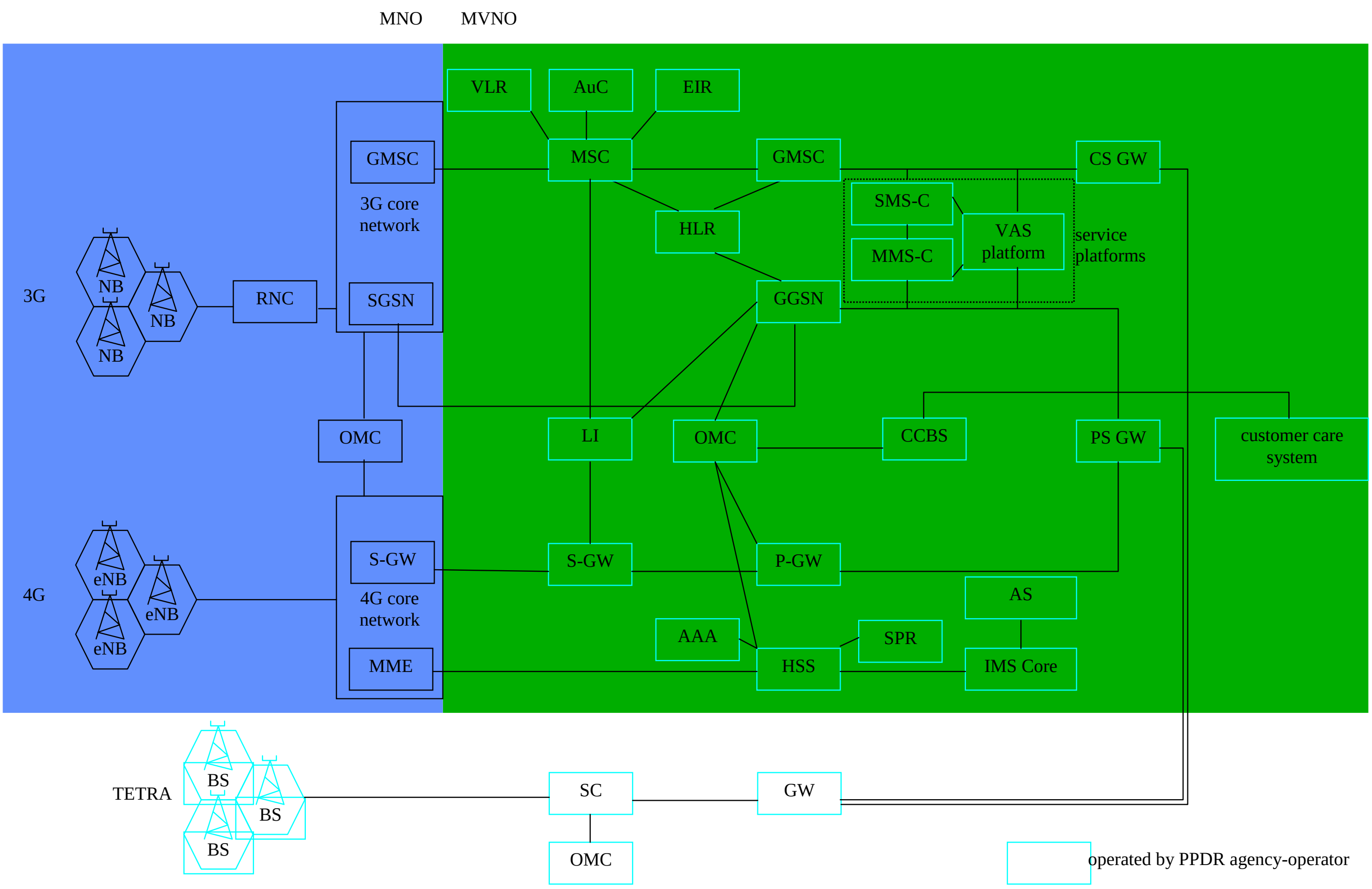

Figure 7: System architecture when PPDR operator is a pure MVNO

Distinction of network elements and processes handled by operators is given in Figure 8.

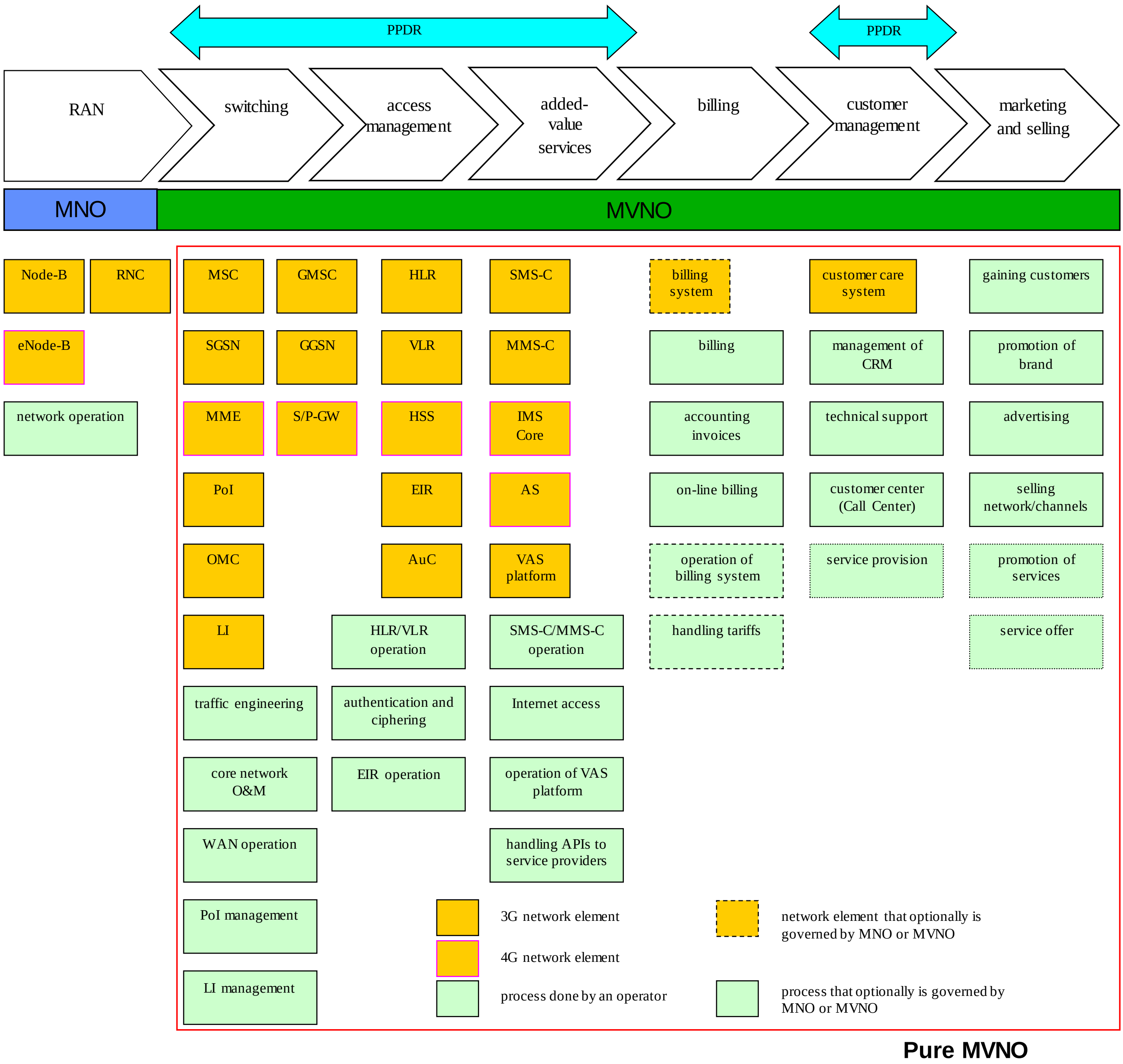

Figure 8: Value-added chain for pure MVNO

Advantages and disadvantages of this architectural solution are summarized in Table 4 below:

Advantages	Disadvantages
Moderate CAPEX	Some boundaries on the transfer volume can be established by MNO
Quicker deployment than building the network by own	Moderate OPEX
Mission-critical voice services are secured using PMR network	Low network availability during crisis events due to congestion in CMNO's infrastructure
In non-critical cases RAN can be used for voice and data to increase overall capacity	Coverage depends on CMNO
Security can be hardened using own core	No priority of services for PPDR

Advantages	Disadvantages
network	agencies
Easier to deploy new services	Lack of resilience in RAN leading to low availability

Table 4: Advantages and disadvantages of sharing RAN by Pure MVNO to provide broadband services to PPDR agencies

5.2.2 Commercial Operator for Voice and Data services

CMNO provides mission-critical voice AND data services. In the UK, this model involves deploying pre-standard VoLTE solutions.

This option is quite similar to the Option 4, but instead of being operated by a PPDR agency (or PPDR operator), the network operation and deployment is the responsibility of a Commercial MNO. CMNO would need to update and harden their current infrastructure and will use dedicated spectrum to provide access to PPDR users.

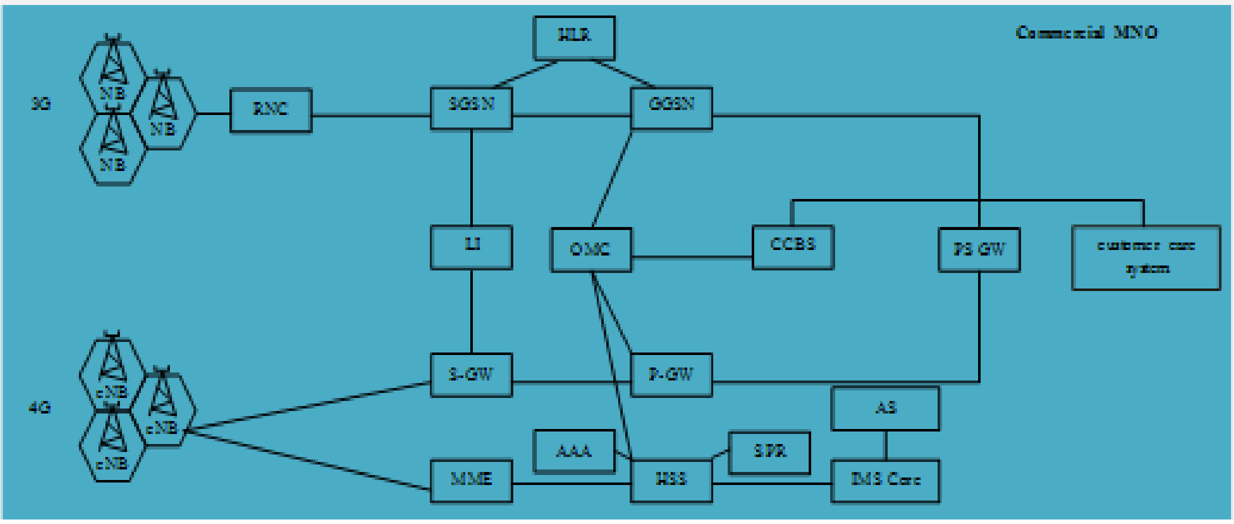

Figure 9: System architecture when a commercial operator deploys and operates a broadband network for PPDR usage

There are only two sub-networks used both for mission-critical voice and data. Current voice mission critical voice services provided by legacy TETRA/TETRAPOL have to migrate to Broadband Cellular LTE:

- 3G, one operated by MNO,
- 4G, one operated by MNO,

The 3G sub-network consists of (a) RAN composed of Node-B (NB) base stations and Radio Network Controllers (RNC), and (b) core network consisting of Serving GPRS Support Node (SGSN), Gateway GPRS Support Node (GGSN), and Home Location Register (HLR).

The 4G sub-network consists of (a) RAN that composes of Evolved Node-B (eNB) base stations, and a core network where there are Mobile Management Entity (MME), Serving Gateway (S-GW), Packet Date Network (PDN) Gateway (P-GW), Home Subscriber Server (HSS), Authentication, Authorization and Accounting (AAA), Subscription Profile Repository (SPR), IMS (Internet Protocol Multimedia Subsystem) Core, and Application Servers (AS).

Moreover there are some common elements for 3G and 4G sub-networks like backhaul network, backbone network, Lawful Interception (LI), Operation and Maintenance Centre (OMC), Customer Care and Billing System (CCBS), Packet Switch Gateway (PS GW).

An assumption is made about a full migration to broadband for all PMR services. Compared to previous options, no legacy TETRA/TETRAPOL sub-network is considered anymore.

All elements and processes are handled by the Commercial MNO as illustrated in Figure 10. In fact, because neither PPDR operator, nor legacy narrow band network are involved, everything is handled by the Commercial MNO.

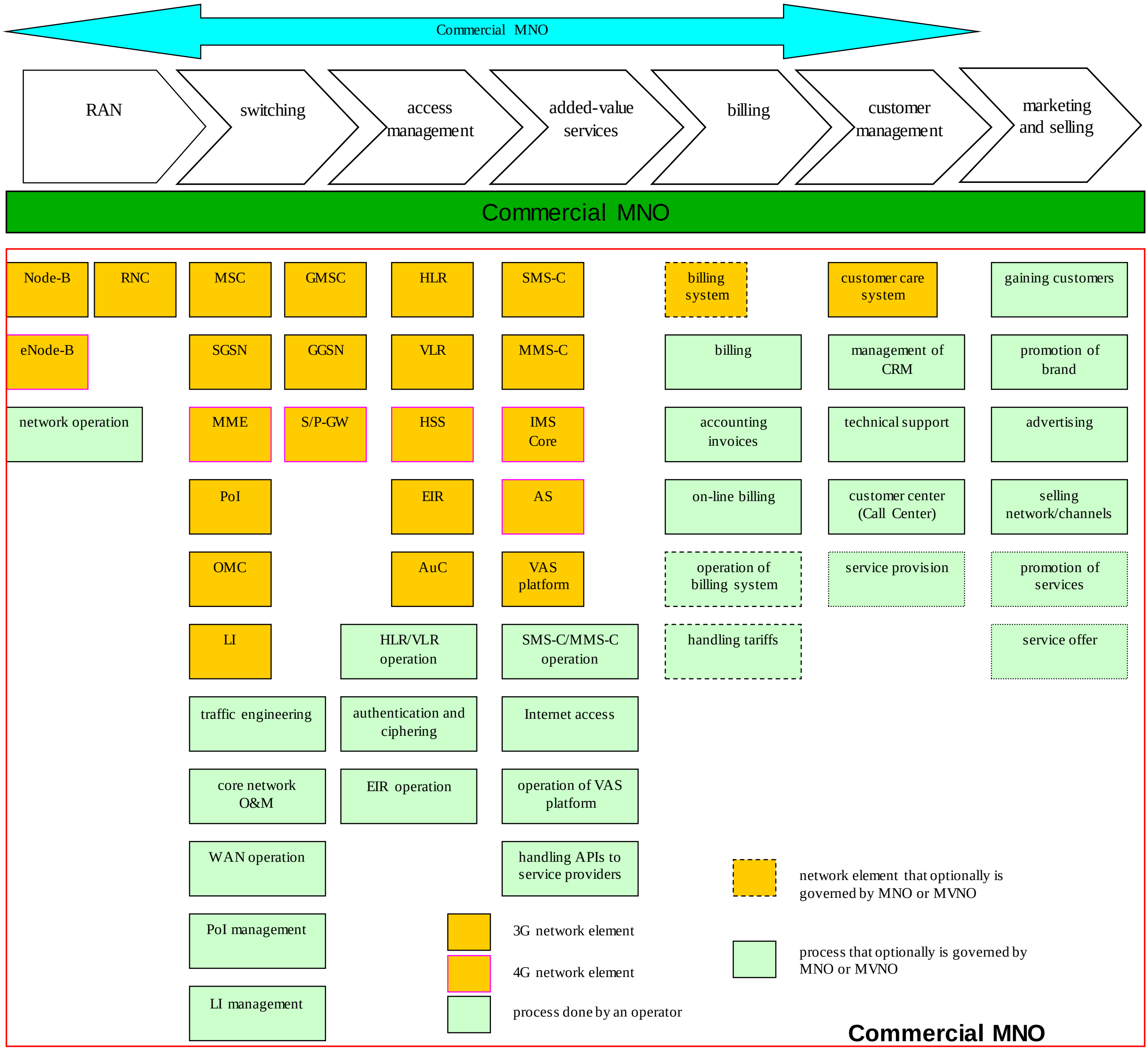

Figure 11: Value-added chain for Commercial MNO option

Advantages and disadvantages of the considered option are summarized in Table 5.

Advantages	Disadvantages
Almost no CAPEX, deployment is under the Commercial MNO responsibility.	Commercial mobile networks and operations must be upgraded for mission-critical communications. Current CMNO network technology with LTE (and 3G UMTS) does not yet support the key demands of mission critical users with the specific features necessary

Advantages	Disadvantages
Quick deployment, as Commercial MNO may re-use their current infrastructure	For many Mission Critical users to employ the MNOs, their commercial behaviour would have to be modified with specific changes to CMNO core business model
Commercial MNO expertise	Very strict and specific regulatory structure is required to assure Commercial service level commitment
	This model involves deploying pre-standard VoLTE solutions as soon as they are available for mission-critical services

Table 5: Advantages and disadvantages of using a Commercial MNO for PPDR

5.3 Business Models

The need for broadband services and interoperability among various communication systems being expressed by PPDR organizations in Europe and worldwide, as well as the significance of the effective operation of public safety services commonly recognized in the countries, open perspectives for near future investments in the area of Public Safety Communications (PSC). The decisions on the procuring or upgrading the PPDR systems will be based not only on the technological features but also on financial, economic and organizational analysis. Regarding this, several business models with relevant sub models can be identified.

There are many approaches to how new networks based on broadband systems can be acquired. The dominant strategy is to build the network by its owner. However, the owner has to be neither an operator nor a user of the further network. In such a case it often happens often that a governmental body sponsors the investment in order to acquire the network dedicated for many state organizations whose efforts are focused to ensure the public safety. Another approach is to lease transmission services from dedicated or public operator who builds the network and then provides services to PPDR users on the basis of a monthly fee. In this case a PPDR organization bears only limited CAPital EXpenditures (CAPEX) because the majority of expenses constitute the OPerational EXpenditures (OPEX).

The other issue that has to be considered by the decision maker is to make a proposal how the new network will be operated. Once more the owner can be the operator who is responsible for operation, management and maintenance of the network. However, the operator may also engage an external company that will do one or many tasks listed above. In this approach the outsourcing may increase the quality of operational tasks and allow PPDR organization to focus on its main duties. An alternative approach for the strategy of network operation is when an owner hires a dedicated Mobile Network Operator (MNO) who can provide services to end users directly or to Mobile Virtual Network Operators (MVNO) who becomes a representative of end users.

One of the dimensions that should be optimized when a PPDR organization decides to acquire the network is CAPEX. The investment in the new broadband infrastructure is very costly especially if the network is to be used by a limited number of end users. That is why it is preferable to split CAPEX among many organizations. On the other hand, in order to limit CAPEX one can select an OPEX-oriented model but it is very unlikely that Total Cost of Ownership (TCO) may be reduced in this case. It results from service provider's business model that assumes that the investment has to be returned and simultaneously such an operator has to profit.

CAPEX strongly depends on a number of base stations so it has been looking for frequency bands as low as possible in order to maximize the coverage of a base station. The investment expenditures can be reduced if the operator has already had the mast infrastructure. It also accelerates the deployment process because many permits have been already issued for existing masts.

Experience and know-how of the investor are the other problem. To plan and deploy the network the PPDR organization needs experts who are qualified to discuss with system manufacturers and network engineers. That is why it is preferable sometimes to commission whole process of project management to a substitute investor or contract engineer who has sufficient competencies.

Operational costs are the other dimension that has to be taken into consideration if a new PPDR network is to be acquired. If someone decides to lease broadband services from existing private or public operator, the OPEX part of the undertaking increases.
Once more high skilled staff is needed to operate the network itself. If such competencies are not available in the PPDR organization, a typical strategy is to outsource them. However, in many areas of operational workings, the in-sourcing is preferred due to security and safety constraints. Moreover, one can ensure a vocational progress of the own staff.

In order to compare different business models elaborated by PPDR organizations during their analyses, one can use CAPEX, OPEX, TCO and other typical indices of efficiency, e.g. Net Present Value (NPV) and Internal Rate of Return (IRR). For economic issues the other group of comparative quantities can be applied by an analyst, e.g., Benefit-Cost ratio and Dynamic Generation Cost. One can also use a more descriptive way based on Strength, Weakness, Opportunity and Threat (SWOT) analysis.

The notion of a business model is mostly used in the context of an abstract company and its revenue[11]. The elements used to construct business models reflect the broad range of options analysed by the PPDR-TC consortium, including a range of actors as well as value and cash flows, though the dominant view is supposed to be that of a PPDR service organization. The key types of elements for the proposed business models are products or services, actors or entities, resources and capabilities, and finances[12]. Other analysed aspects include geographical scope and future trends.

In our approach, we consider three general business models suggested for implementation of critical communications broadband services.[13] They can be identified as:

1. **User Owned – User Operated (UO-UO)**: Building, ownership and operation of the network(s) by the end-user agency (or agencies) themselves.
2. **User Owned – Commercial Operator (UO-CO):** Building and ownership of the network(s) by the end-user agency (or agencies). Operation of the network(s) by a commercial provider of outsourced managed network services.
3. **Commercial Owner – Commercial Operator (CO-CO):** User agencies subscribe for services provided by a commercial network owner / operator.

In Table 6 the simplistic relative cost levels to PPDR agencies of each of these three business model options in CAPital EXpenditures (CAPEX) and OPerational EXpenditures (OPEX) terms are presented.

Business Model	CAPEX	OPEX
UO-UO	High	Low
UO-CO	High/Medium	Medium
CO-CO	Low	High

Table 6: Relative CAPEX and OPEX Costs for the Business Models of PPDR Systems

The business models presented above will impact the financial options to be considered. The investment financing strategy may generally come from: (a) public-private partnership (PPP), (b) own funds to build the network, (c) leasing, (d) credit.

[11] B. W. Wirtz, Business Model Management. Gabler Verlag, 2011.
[12] P. Timmers, "Business models for electronic markets", Electronic Markets, vol. 8, no. 2, 1998.
[13] P3 Communications GmbH, "LTE for critical communications drivers, benefits and challenges", White Paper.

Regarding implementation options, we follow models of network acquisition reported by CEPT ECC FM49 Radio Spectrum for PPDR working group[14]. The general implementation options can be stated as:

A. Dedicated network infrastructure for PPDR,

B. Commercial network(s) infrastructure providing broadband services to PPDR users,

C. Hybrid solutions with partly dedicated and partly commercial network infrastructure.

In Figure 12 a model overview for PPDR network acquisition is depicted. Orange labels in this figure illustrate to which general business model each acquisition sub-model belongs to.

It is not known yet whether hybrid solutions could be used with confidence for mission critical communications because the commercial part of the network may not meet the same stringent PPDR requirements as the dedicated one. However, it seems a reasonable assumption that the commercial solution will satisfy the non-mission critical data transmission needs of the PPDR users within the area covered by the commercial network(s) used even without any additional resilience, priority or other specific functionalities to treat PPDR users differently from other users.

In the following subsections we will briefly characterize the above mentioned three acquiring models with appropriate sub-models.

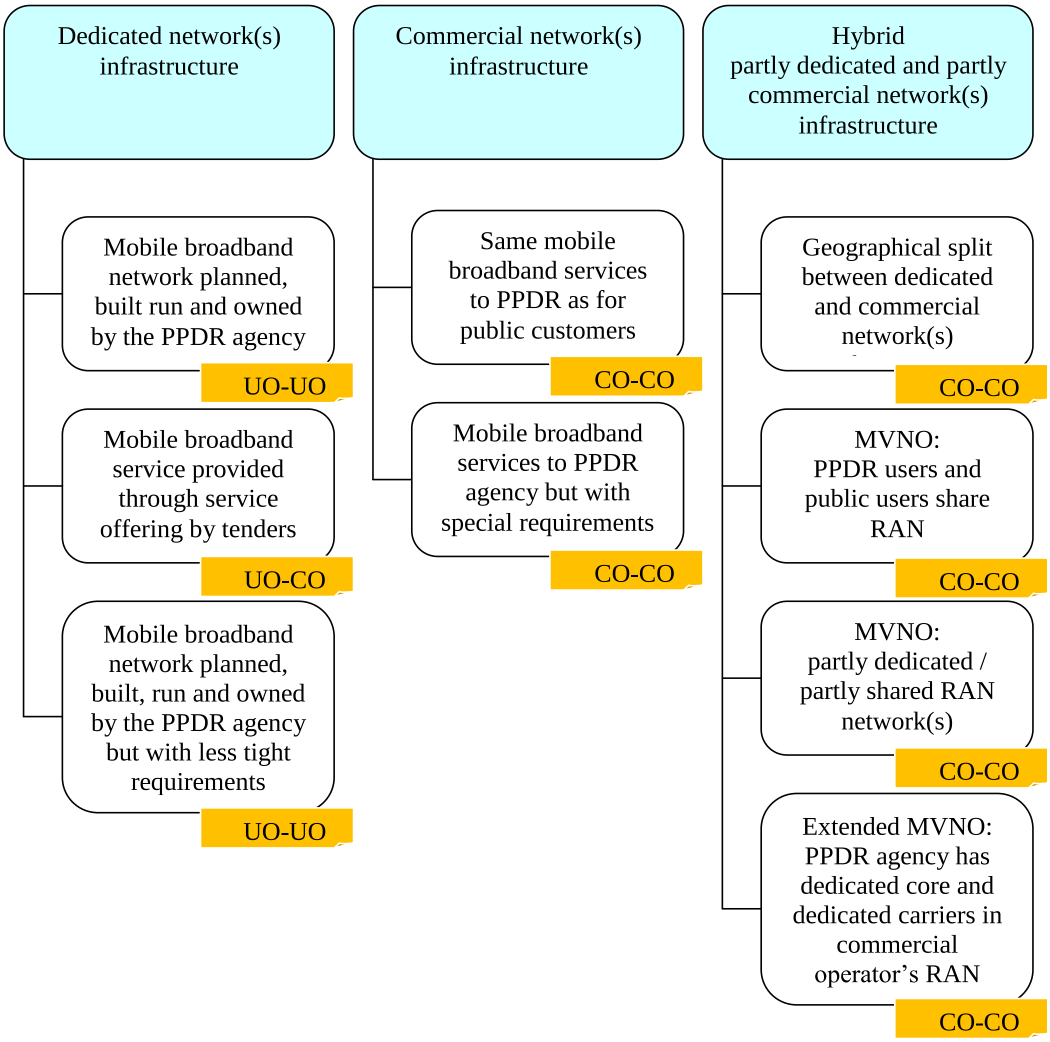

Figure 13: Model overview for PPDR system acquisition

[14] CEPT ECC Radio Spectrum for Public Protection and Disaster Relief (PPDR) working group, FM49 (14) 008rev1 Network Types part (Draft ECC Report B).

5.3.1 Dedicated Network Infrastructure for PPDR

In this model, a dedicated PPDR mobile broadband network is specifically designed to meet PPDR service requirements. Such a network is expected to be designed similarly to current TETRA (TErrestrial Trunked Radio) and TETRAPOL networks in Europe. In this design, the use of the commercial mobile network infrastructure is limited. There can be two sub-models of such an acquisition model based on dedicated network:

5.3.1.1 Sub-Model 1.1: Mobile broadband network planned, built, run and owned by the authority

This sub-model is related to the generic UO-UO model. It means that the authority sets the technical requirements to the network infrastructure with respect to PPDR services requirements, finances the equipment and supporting infrastructure, the operation and maintenance support systems and pays the running cost (lease cost, operation and maintenance cost and spare parts). An authority project like this might also include end-user radio terminals and the public safety agencies control room equipment.

5.3.1.2 Sub-Model 1.2: Mobile broadband service provided through service offering

This sub-model is related to the generic UO-CO model. In this acquiring model, the authority buys the mobile broadband services from a commercial company according to technical requirements set to the services offered with respect to service requirements. In this model the prerequisite is that the service offered is delivered through a dedicated mobile broadband network. The new network is delivered by the commercial operator based on a turnkey contract.

5.3.1.3 Sub-Model 1.3: Mobile broadband network planned, built, run and owned by the PPDR agency but broadband service meets less tight requirements

This sub-model is related to the generic UO-UO model. It is similar to sub-model 1.1 but requirements for system functionalities in the domain of broadband transmission are less strict. This model corresponds to systems currently used by PPDR agencies in most countries in Europe (e.g. in Romania) since typically they deploy rather wideband systems.

5.3.2 Commercial Network(s) Infrastructure Providing Broadband Services to PPDR Users

In this acquiring model, the authority buys mobile broadband services from a commercial mobile network operator. The PPDR 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. There exist two variants of broadband deliveries to PPDR users from a commercial network.

5.3.2.1 Sub-Model 2.1: Same mobile broadband services to PPDR as for public customers

In this scenario the PPDR users will get the same service as the public, i.e. the other users of the network. No special requirements to the service offering or to priority of service exist, with the exception of potential national roaming if that has been agreed.

5.3.2.2 Sub-Model 2.2: Mobile broadband services to PPDR with special requirements

In this sub-model the authority will buy mobile broadband services to PPDR users from one or several commercial mobile network operators. The idea is that the mobile broadband services are delivered by the same network infrastructure as the commercial operator uses to deliver services to the public, however, the authority has special requirements to both services provided and Quality of Service (QoS). This means that the commercial operator has to support special services, e.g. group calls, potentially extra security facilities and increased levels of availability through increased robustness in the network design (that will be to the advantages to all the operators' customers) and priority to the PPDR users.

5.3.3 Hybrid Solutions with Partly Dedicated and Partly Commercial Network Infrastructure

The idea behind the hybrid solutions is to jointly exploit the commercial mobile broadband network infrastructure and satisfy the need the PPDR users have for availability and capacity in daily operation as well as in periods of disaster and/or big planned and unplanned events when commercial networks often fail to deliver and/or are overloaded. A shared infrastructure solution is regarded as a viable option to deliver mobile broadband PPDR services in the future. It is known that nowadays the cost of building dedicated mobile broadband solutions for PPDR in low populated areas may be regarded to be too expensive. One way to overcome this for PPDR users is to utilise commercial mobile broadband network infrastructure and existing coverage in those areas. There are several substantially different ways how the mobile broadband network infrastructure sharing can be done. These sub-models are the following:

5.3.3.1 Sub-Model 3.1: Geographical split between dedicated and commercial network infrastructure

With this acquisition model based on a sharing design the idea is to build dedicated mobile broadband network for PPDR in some parts of a country, e.g. in the most populated areas and most important roads, and to buy broadband service from one or more commercial mobile operators for the remaining part of the country.

This geographical split requires dedicated spectrum in the network part serving PPDR users only and a roaming agreement between the PPDR network and the relevant commercial network(s).

5.3.3.2 Sub-Model 3.2: Mobile Virtual Network Operator (MVNO) model where PPDR users share Radio Access Network (RAN) with the public users

With this acquiring model based on a sharing design the idea is to build a dedicated core and service node part of the mobile broadband network for PPDR organizations. The full MVNO model with dedicated core and service infrastructure for the PPDR users will enable the PPDR operator to have full control of the PPDR users with respect to their subscriptions, service profiles, service offerings and security key distribution. The RAN (transmission, housing, masts, power, air conditioning and telecom radio base station electronics) is shared by PPDR and public operator(s) across the whole operational region/country. This model is planned to be used in Belgium by Astrid and in Sweden to provide mobile broadband to PPDR users.

5.3.3.3 Sub-Model 3.3: MVNO model with partly dedicated / partly shared RAN network

With this acquisition model based on a sharing design the idea is to build a dedicated core and service node part of the mobile broadband network for PPDR users to cover the country (like in sub-model 3.2). In some parts of a country, i.e. in the most populated areas and along the most important roads PPDR entities will have its own RAN telecommunication infrastructure. Elsewhere, the service is provided by the RAN of one or several commercial operators.

This model requires that the PPDR organizations will have to have relevant spectrum resources available where they have dedicated RAN telecommunication infrastructure (like in sub-model 3.1).

5.3.3.4 Sub-Model 3.4: Extended MVNO model where PPDR organizations have dedicated core and service nodes and dedicated carriers in the radio transmitters / receivers in the RAN part of the commercial mobile broadband network

This is an extended full MVNO model where PPDR organizations have dedicated core and service nodes and dedicated carriers (for radio transmitters / receivers) in the RAN part of the commercial mobile broadband network. With this sharing design the idea is to build a dedicated core and service node part of the mobile broadband network for PPDR to cover the country (like in sub-model 3.2). In the RAN part the idea in this model is that on the one hand PPDR entities utilize the transmission lines and base station buildings and supporting infrastructure (masts, power supply, climate control and other telecommunication infrastructure hardware like shelves) from one or more commercial operators and that on the other hand they have also dedicated carriers (allocated to radio transmitters / receivers) in the commercial mobile base stations all over the country. In this model the assumption is that the functionality to have separately controlled radio carriers (from two different core networks) in a base station is implemented in a stage of the network design.

This model requires that the PPDR organizations will have relevant spectrum resources available nationwide (like in sub-models 3.1 and 3.3).

This will give the PPDR users dedicated communication capacity in the whole land area but they will be dependent of the robustness of the RAN handled by the commercial network(s).

6 Recommendations for Decision Makers – How to Migrate?

6.1 Business strategies and Economic sustainability

PPDR organizations would like to benefit from development of mobile technologies and to use broadband services for operational purposes needed in different scenarios. It seems that future PPDR networks will be based on LTE (LTE-Advanced) technology but existing narrowband networks will be still operated due to their maturity. Nevertheless, LTE technology has to significantly evolve soon in order to meet PSC requirements. Works in this topic are done by 3rd Generation Partnership Project (3GGP) as well as by TETRA and Critical Communications Association (TCCA). From practical perspectives one can notice that video transmission is a main benefit from new broadband networks.

For all business sub-models presented in Section 0 NPV values are less than zero. It is because PPDR agencies are public organizations without any incomes due to security needs and political reasons to be independent. ENPV are positive. It means that all sub-models are profitable for public PPDR agencies.

Sub-models 1.1 and 1.3 are based mainly on CAPEX whereas sub-models 1.2, 2.1 and 2.2 − on OPEX. The remaining sub-models (3.1, 3.2, 3.3 and 3.4) are mixed variants of capital and cost expenditures. The CAPEX-based models tend to give better results, i.e. lower overall costs. The reason for that is a large number of terminals which are very expensive in OPEX-based sub-models where monthly fee is paid. If a less number of users is considered, OPEX-based models may be more profitable.

It seems that although certain migration to broadband networks based on LTE/LTE-A standard narrowband transmission will be still available using TETRA/TETRAPOL networks. Leasing the network (scenario 1.2) or the services (scenarios 2.1-2.2) is the most expensive option. Scenarios 3.1-3.4 are attractive approaches to acquire a PPDR network. An additional advantage of the latter ones is that the responsibility for the network is split between PPDR entity and commercial operator(s).

Due to vast expenditures needed to migrate to the new network which RAN needs many base stations to cover the country, a trend can be observed to re-use commercial mobile networks as much as possible according to SLA contracts and with respect to security and resiliency needs. On one hand availability of commercial mobile networks is limited because they are public networks, but on the other hand the investments borne by PPDR bodies can be reduced.

The efficient indices of the project how a PPDR system can be acquired depend on many factors. The needed coverage and a number of end-user terminals are the most important parameters. In the scenarios where any commercial operator is involved, co-operation costs expressed by SLA have appeared to be the most significant ones. It is also a time consuming activity that has to be done with all operators that are involved in providing the services. Such hybrid approaches are attractive for new broadband infrastructures but they need detailed planning, fruitful negotiations to sign good SLAs, and tangible technical and organizational solutions that can harden the usability of public network in order to ensure many non-functional requirements needed for efficient mission-critical PSC even when crisis events occur. These hybrid models can be based on full MVNO. The real challenge is to build a nationwide PPDR network. The coverage of whole country with a broadband network is feasible but will be very difficult to achieve due to CAPEX. A lack of attractive frequency bands that allow allocate many radio channels of larger bandwidth is one of the disadvantage reasons. The most promising band is 700 MHz but its use depends on existing license reservations in each country and needs even several years to the re-allocation for purposes of PPDR networks.

It is also worthy to mention that evolution of PPDR networks skips 3G-like technologies because the migration path goes directly from 2G-like networks (TETRA/TETRAPOL) to 4G-like ones (LTE/LTE-A). That is why an acquisition of new PPDR networks should be planned to ensure very long time of their operation. It seems that the project's sustainability ought to be longer than 15 years. Alignment of both PPDR and commercial networks based on the same 4G technology is an additional advantage for further evolution. However, technical solutions to meet PPDR requirements and services remain a challenge. It takes a few years till they will reach a status of mature services and PPDR users will be able to rely on them because the packet switching based on IP transmission is less predictable than the traditional circuit switching current used for voice communication in PPDR networks.

6.2 Spectrum Management

There is a growing global consensus that additional spectrum is required for PPDR mobile broadband communications. Ideally this should comprise both low frequency (sub-1 GHz) spectrum to optimise wide area coverage in a cellular network configuration and higher frequency spectrum (in the 1 - 6 GHz range) to support localised high traffic volumes at major events or incidents[15]. Preferred spectrum for future PPDR systems is likely to lie in the 700 MHz range for wide area cellular deployments and around 5 GHz for localised "hot spot" use.

In addition, spectrum is also likely to be required for specialised applications such as A2G communications and DMO between terminals. Because A2G communication typically involves a line of sight transmission path higher frequencies may be used and currently the favoured frequencies appear to be in the 2.3 GHz and 3.5 GHz ranges. However, in the future these frequencies may be increasingly in demand for commercial cellular activities.

As far as possible PPDR terminals should be capable of operating on both dedicated PPDR network infrastructure where it exists and on commercial cellular networks. Use of cross-sector technologies like LTE or Wi-Fi in frequency bands that lie either within or adjacent to existing commercial bands should help to facilitate such interoperability.

The table below (Table 7) summarises the most likely future spectrum resources for broadband PPDR services in Europe at the time of writing, based on publicly available literature and discussions within regulatory fora, notably CEPT and ITU-R.

Application	Preferred band(s)	Comments	References
Wide area cellular network	700 MHz (698-738/ 758-803 MHz)	Up to 2x10 MHz required but equipment should tune over full band to facilitate interoperability with commercial networks. Lower 2x5 MHz has been mooted as a potential harmonised PPDR band	ECC Report 218, ITU-R document 5A/265
Local area / ad-hoc networks	4940-4990 MHz and 5150-5250 MHz	Higher band is shared with commercial Wi-Fi. May also be used to support direct mode operation	CEPT ECC Recommendation (08)04
Air to ground	2300-2400 MHz	Based on current utilisation in some	CEPT,

[15] WIK-Consult, Final Full Public Report, PPDR Spectrum Harmonisation in Germany, Europe and Global, J. Scott Marcus et al., 6 December 2010

Application	Preferred band(s)	Comments	References
(A2G) communications		countries	National Regulatory Authorities

Table 7: Preferred bands for future PPDR deployment in Europe (as of May 2014)

6.3 PPDR-TC General Recommendations

The PPDR-TC recommendations are grouped into the following subject areas:

1. Wireless technology compliance recommendations (WTC)
2. PPDR network technical characteristics recommendations (TC)
3. Economic & procurements recommendations (EP)
4. Spectrum recommendations (SR)

PPDR-TC produced the following recommendations which can be addressed to standardization bodies, mainly to the groups involved in PPDR communication standards.

Code	Recommendation title	Targeted organisations	Timeline for implementation
WTC1	Wireless technologies combination for PPDR communications	National Regulators; procurement groups	Short to medium-term
WTC2	Usage of a single wireless technology for PPDR communications	National Regulators; Standardization Bodies[16]; industries; PPDR agencies	Medium to long-term
WTC3	Deployment of Mobile Ad hoc Networks technologies for high demand PPDR communications	National Regulators; procurement groups	Short to medium-term
EP1	Hybrid MNO/MVNO business models	PPDR agencies (national and regional levels); MNOs with deployed LTE networks	Short-term
EP2	Recommendation EP2: MVNO business models	National Regulators; MNOs with deployed LTE networks	Short to long-term
EP3	Differentiated Quality of Service (QoS) for PPDR users using commercial networks	PPDR agencies	Short-term
EP4	Coexistence with existing networks	PPDR agencies	Short to long-term
EP5	Other Economic & procurements recommendations	PPDR agencies	Specific to PPDR needs
SR1	PPDR spectrum allocation based on “flexible harmonization”	National Regulators / Procurement groups.	Short to medium-term
SR2	Identify harmonised frequencies for Device-to-Device and Air to Ground Communication	National Regulators / CEPT.	Short to medium-term

[16] The standardization organizations identified as possible targets of the PPDR-TC recommendations are:
1. International Telecommunication Union (ITU)
2. Conference of Postal and Telecommunications Administrations (CEPT)
3. European Telecommunications Standards Institute (ETSI)
4. 3rd Generation Partnership Project (3GPP)
5. EU Radio Spectrum Committee (RSC)

Code	Recommendation title	Targeted organisations	Timeline for implementation
TC1	Rapidly deployable resilient MESH networks	Network operators; PPDR procurement groups; System integrators; Vendors	Short to medium-term
TC2	Rapidly deployable WiMAX networks	PPDR procurement groups; system integrators	Short-term
TC3	Resilience capabilities of deployable ad-hoc LTE networks	Network operators; system integrators	Mid-term
TC4	Resilience capabilities of deployable ad-hoc LTE networks (Transport Protocols)	Network operators; system integrators	Short-term
TC5	Resilience capabilities of deployable ad-hoc LTE networks (SDN)	Network operators; system integrators	Short to mid-term
TC6	Improvement of end-to-end performance of network composed of LTE base stations with Satcom backhaul	Network operators; system integrators	Mid to long-term
TC7	Joint Device-to-Device (D2D)/Multicast for Push-to-Data services in LTE	PPDR network manufacturers, System integrator, PPDR system operators	Short to mid-term
TC8	Mobile Cellular Ad-hoc LTE	Standardization body targeted: 3GPP Isolate E-UTRAN work item (IOPS); PPDR system integrators	Mid-term

Table 8: PPDR-TC General recommendations

6.4 Migration Strategies

The research completed by the PPDR consortium produced a set of guidelines for a possible roadmap towards the adoption of future communication technologies, namely moving from TETRA and GSM/3G based landscapes, towards the long term vision of a full featured LTE based environment capable of supporting the PPDR community mission critical requirements.

The presented roadmap concludes that all the other technologies should be considered as niche technologies. As such they should be considered by the PPDR community as a means to extend the capability of the PPDR community in very specific scenarios, and not so much as a technology to be used in typical routine operations, i.e. the day-to-day operation scenario.

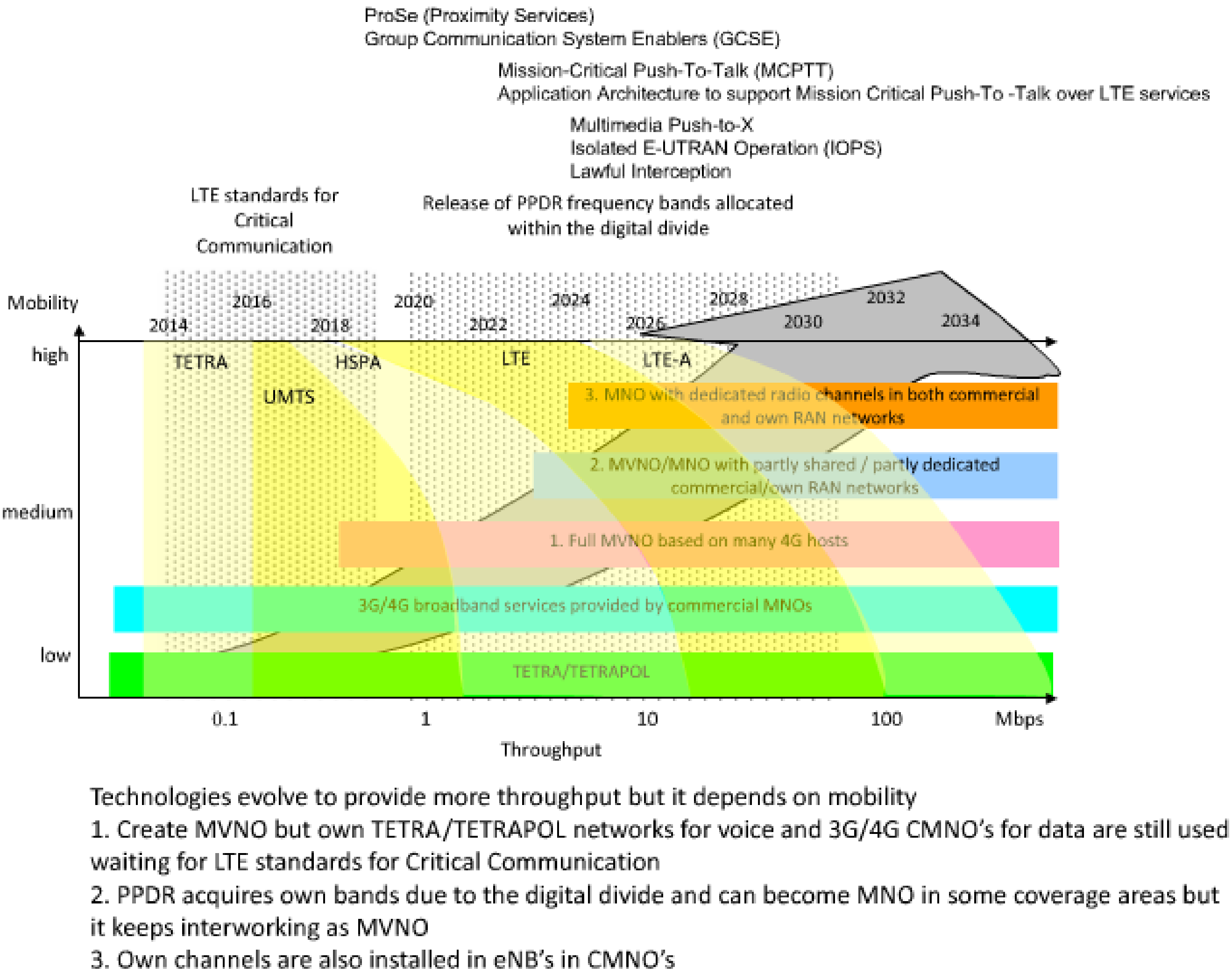

Figure 14: Roadmap – first, second and third steps in the migration path

The PPDR-TC researchers' vision for the short term (5 years from now), is not very ambitious and solely considers the use of the LTE services to accommodate the broadband services. The medium term vision depends on the establishment of an LTE standard for the mission critical voice communication over LTE. Therefore in the medium term, 10 years from now, the existing TETRA system will be close to their end of life and their operation is ensured, not by refurbished TETRA technology, but rather by the adoption of LTE based solutions capable to interoperate with the existing TETRA infrastructure. Finally, the long term vision, i.e. the scenario envisaged in 15-20 years from now, assumes that the LTE mission critical capabilities is now a mature technology and has surpassed the rigorous scrutiny of the end user daily utilisation for all possible scenarios, over the most remote regions. By then LTE has slowly but reliably replaced the TETRA technology as TETRA systems naturally became obsolete and incapable of delivering the prominent need for broadband services.

The spectrum allocation requirements need to be taken into consideration as the use of a public infrastructure should ensure that the available spectrum may accommodate the PPDR mission critical services. Alternatively, the PPDR community may pursuit a strategy of using pre-dedicated spectrum bands, 100% dedicated to mission critical operations. However this can easily translate into higher operation costs as the public infrastructures would not have an interest in operating in bands that the general public is not using. Therefore, the spectrum regulatory authorities need to take into consideration the needs of the PPDR community whenever regulating the available bandwidth for the LTE services, otherwise the use of a band common to public and PPDR services may not be an option.

An mentioned earlier, other technologies, such as WiMAX, Wi-Fi and MANET networks, have been considered as niche technologies but they're still capable of enhancing the existing communication capabilities in very specific situations, namely in situations where existing communication infrastructure is not operational, or unable to cope with the need for additional traffic. Those situations are mostly found in operational scenarios designated by the PPDR researcher community as unplanned events of planned major events. The roadmap takes these technologies into consideration for the short, medium and long term stages, as these technologies may deliver significant benefit to the PPDR end-user community in very specific scenarios where the use of LTE technology is not possible or economically unfeasible.

Finally, to support the user in the decision process concerning all the available options, the PPDR-TC research community published a web-based tool that incorporates all the proposed guidelines. The tool allows the PPDR agencies to specify their specific needs and after cross-referencing those requirements with the roadmap baselines and other PPDR research results, the tool ultimately delivers a set of options for the PPDR-TC agencies to consider in their evolution plans.

7 Conclusions

This publication addresses and critically discusses the debating subject of the next generation (broadband) PPDR communication systems, as the need for migration from current deployments is evident on behalf of the typical users, namely the Public Protection and Disaster Relief agencies. To this direction, consensus and understanding is not only needed on the technology to be adopted but most importantly on the special characteristics of such proposed solutions, posing numerous challenges at nation and EU levels. Spectrum management and specifying most efficient deployment models are the two main matters that will, in large extent, define and shape the PPDR communication systems of the future. Noteworthy, both matters are correlative to political, economic and geographical constraints and to surpass them is by far not a trivial case. The scope of this publication is to provide the policy and decision makers of the PPDR community at national and European levels, the background, tools and knowledge for making informed decisions on such path to migration.

By referring to the PPDR communication ecosystem as of today, we identify user needs by designing and presenting the scenarios, services and applications that the practitioners demand. Moreover, given the multitude of services and applications of different maturity and addressing different scenarios we further classify them depending on the time expected to be fully operational in PPDR communication systems. By doing so and in conjunction to technology review we are in a position to identify present gaps and misfits and thus propose for the candidate technologies to be adopted by the PPDR community, them being LTE, Wi-Fi and MANETs.

However, even if the technology choice could be established the barrier of spectrum management and band allocation remains. The spectrum landscape is diverse at a global level and Europe is not an exception. A European PPDR frequency band harmonisation (the US example) seems as the perfect solution but this debate is not expected to shortly conclude as different approaches remain on the table by several European nations. Nonetheless, significant efforts are being made and recently the selection of the 700 MHz spectrum band has been established by CEPT for hosting future (broadband) PPDR services. It should be noted though that it remains up to the national bodies to allocate such band either commercially or solely for PPDR purposes.

Another matter that will largely influence future PPDR deployments is the architectural and business models to be adopted. In this domain, diversity of solutions is even greater and to select the most effective and viable model is not an easy choice, as handling of CAPEX and OPEX of the network deployment can be managed commercially (hence generation of profit is expected) or publically.

All above facts have led us in the production of recommendations towards decision makers for constituting the next generation (broadband) PPDR communications systems. These recommendations define propositions for solutions that are technically sound on the provision of enhanced services, economically sustainable as migration requires a big rollout phase and spectrum efficient considering that spectrum is scarce and is utilised on many different communication applications as well.

The authors' vision is that the analysis, critical discussion and recommendations presented herein shall provide policy and decision makers with an additional tool at their disposal for the choices need to be made on the migration path towards successful deployments of next generation (broadband) communication systems.

Acronyms & Abbreviations

A2G	Air to Ground
CAPEX	Capital Expenditure
CCC	Command and Control Centre
CMNO	Commercial Mobile Network Operator
COTS	Commercial off the shelf
DGNA	Dynamic Group Number Assignment
DMO	Direct Mode Operation
FDD	Frequency-division duplex
GIS	Geographic Information System
GPRS	General Packet Radio Service - a packet oriented mobile data service on the 2G and 3G cellular communication systems
GSM	Global System for Mobile communications - a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation (2G) digital mobile communications
HSPA	High Speed Packet Access - combination of High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA), that extends and improves the performance of existing 3G mobile telecommunication networks
LTE	Long Term Evolution - a standard for high-speed wireless communication for mobile phones and data terminals
MANET	Mobile Ad hoc Network
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
OMC	Operations and Maintenance Centre
OPEX	Operating Expenditure
PMR	Professional Mobile Radio
PPDR	Public Protection and Disaster Relief
PSTN	Public Switched Telephony Network
PTT	Push to Talk
RF	Radio Frequency

SATCOM	Satellite Communications
TDD	Time-division duplex
TETRA	Terrestrial Trunked Radio
UHF	Ultra-High Frequency (300 MHz to 1 GHz)
UMTS	Universal Mobile Telecommunications System - a third generation mobile cellular system for networks based on the GSM standard
VHF	Very High Frequency (30 MHz to 300 MHz)
Wi-Fi	Wireless local area network - based on 802.11 standard

List of Figures

List of Tables

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