



Security And Interoperability in Next Generation PPDR
Communication Infrastructures



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Abstract: Deliverable 4.3 is focus on the business analysis of next generation PPDR networks detailing the different models with techno-economical analysis. Possible roadmaps are also provided. It is to be noted that this document is an Intermediate version.

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EXECUTIVE SUMMARY

The benefits of broadband capabilities for PPDR users and for the European community is a given. Broadband applications and services will enhance the operational effectiveness of PPDR users. Indeed, broadband PPDR systems will enhance situational awareness (voice, data, video, pictures, sensors...) that will in turn lead to better and timely decisions while improving safety for citizens and PPDR personal.

However, the transition to broadband is not an easy path for PPDR organisations. The challenges that will be faced by PPDR organisations moving to broadband will be technical, cultural, operational, regulatory and economical. The intermediate version of the SALUS business analysis covers the following aspects:

- Existing and emerging technologies roadmap for PPDR - This section focuses mainly on a status of Public Safety LTE standardisation features that would be available (as of today) by early 2016 on paper. This section also gives a regulatory status of dedicated spectrum for broadband PPDR. Major outcome on the topic are expected in upcoming World Radio Conference in November 2015 and will be reflected in the final version of the deliverable.
- Business models – These cover four main classes of models such as commercial MNO, dedicated networks, systems on wheels and a hybrid model. The qualitative analysis provided in this deliverable leads to the conclusion that the hybrid model is probably the best one. Merits of these models will be further analysed in the final version of the deliverable with quantitative analysis using the SALUS Techno Economical tool.
- Possible roadmap migration to LTE – This describes possible preliminary roadmaps covering multiple options for early and late adopters with or without dedicated spectrum. Main conclusions are that migration to full LTE PPDR network may happen between 5 years (early adopters) to 15-20 years (late adopters). This section will be further augmented in the final version of the business analysis deliverable in the light of the enhanced analysis of the technical and business models sections.

It is to be noted that the final version of the deliverable is planned for February 2016.

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1 INTRODUCTION

The benefits of broadband capabilities for PPDR users and for the European community is a given. Broadband applications and services will enhance the operational effectiveness of PPDR users. Indeed, broadband PPDR systems will enhance situational awareness (voice, data, video, pictures, sensors...) that will in turn lead to better and timely decisions while improving safety for citizens and PPDR personal. Besides, broadband PPDR systems will enable automated and remote mobile office duties that will increase presence time of PPDR user on field (the use of broadband in UK proved to increase by 30 minutes per shift per staff the time spent policing in the community [1]). The enhanced effectiveness translates in real life into faster time to resolve crimes, better efficiency in rescuing / saving lives... which also translates into an economical benefit to the society. A recent report from London School of Economics evaluated that broadband for PPDR users could bring a socio-economical benefit around 34 b€ per year across the 28 member states of the European Union [1].

However, the transition to broadband is not an easy path for PPDR organisations. Multiple hurdles are under the way such as:

- *Economical*: deploying a new system with regional / nationwide footprint requires significant investments that need to be secured and planned ahead, a difficult task in current constrained budget and economy across Europe.
- *Regulatory*: deploying a broadband system requires substantial amount of (dedicated) spectrum and although some options are being worked out right now at CEPT level, it is still to be seen if broadband spectrum will be allocated to PPDR in all member states in the short to mid-term,
- *Technical*: Commercial off the shelf (COTS) technologies may not offer today all the desired functionality to turn them into a mission critical system (features, security, scalability, etc). 3GPP and SALUS will contribute towards this goal but they are still a few years away. Besides, deploying and managing a new system based on a new technology will require additional skill set very different from the one available in PPDR organisations today,
- *Change management*: new capabilities will lead to new applications and usage that will impact operational procedures. Intensive training of the PPDR users will be critical to reach full benefits of those new capabilities but also to demonstrate the operational enhancements to get massive adoption from the end-users.

This deliverable explores and discusses the possible ways to evolve from present mode of operations (using specialised narrowband system such as TETRA or TETRAPOL) to future mode of operations based on broadband systems. In section 2, the document describes the current picture and the expected evolution of the key systems that are present today and will tomorrow be part of the PPDR systems (TETRA, TETRAPOL, LTE, Wi-Fi). In particular, the roadmap of the public safety related features from the LTE standard and the regulation status are presented. In section 3, the different business models bringing broadband capabilities to PPDR users (based on dedicated and/or commercial based 4G networks) are given and their respective merits are discussed. Section 4 highlights possible migration roadmap scenarios and are followed by some concluding remarks.

It is to be noted that this deliverable is an intermediate deliverable. The final version will include updates on the standardisation and regulatory front (e.g. taking into account the outcome of WRC-15 on spectrum for PPDR if any, discussing 5G) and will refine the business model options (including e.g. more details on the inclusion of Wi-Fi) and the migration roadmap scenarios with numerical examples based on the SALUS Techno-Economical Tool [2].

2 CURRENT PICTURE AND TECHNOLOGY PERSPECTIVE

This section describes for each technology that will be used in future PPDR networks (TETRA, TETRAPOL, LTE and Wi-Fi), their level of maturity (mainly around standard, deployments and spectrum) to handle PPDR services, their expected evolution path, roadmap and lifecycle.

2.1 TETRA system

2.1.1 Introduction to TETRA

Note: this section is based on information from the TCCA web site [3].

TETRA is an open standard developed by the European Telecommunications Standards Institute (ETSI). The main purpose of the TETRA standard was to define a series of open interfaces, as well as services and facilities, in sufficient details to enable independent manufacturers to develop infrastructure and terminal products that would fully interoperate with each other as well as meet the needs of traditional Private Mobile Radio (PMR) user organisations.

The initial responsibility of ETSI Project TETRA (now known as ETSI Technical Committee TETRA, TC TETRA) was to deliver a set of standards, under a mandate from the European Commission, for a Digital Trunked PMR communications system that could be deployed in Western Europe. As well as producing these mandatory ETSI deliverables (now completed), TC TETRA's responsibility was, and still is, to make sure that the portfolio of standards continue to be developed in accordance with end-user needs and priorities.

The technology solutions chosen to meet user requirements contained in the TETRA standards have been, and continue to be, developed primarily by well-known and respected manufacturers who have been serving the PMR market with products and services for several decades. This combined "Know How" ensures that optimum technology solutions are chosen to meet user requirements.

Although the prime responsibility of ETSI is to develop standards for Europe, many of its standards are also adopted world-wide, as evidenced by the uptake of GSM, the first digital wireless technology standard developed by ETSI. Similarly, the TETRA standard has also become a truly global standard with deployments in all continents of the world, including the US where the Federal Communications Commission (FCC) has recently (2011) granted approval for products conforming to TETRA standard to be available there for business, industrial and transport sectors.

It is also to be noted that actual multi-vendor interworking mainly applies at the air interface level. The interface between the TETRA base stations and TETRA switch is proprietary as well as the interface to the dispatcher stations. Consequently, PPDR organisations are using single source supplier TETRA solutions for the infrastructure but can benefit from different vendors for the terminals. Also, TETRA systems from different vendors are usually not interoperable (although a specification for Inter System Interworking ISI exists), which make cross border operations difficult even when two neighbouring countries are using TETRA systems.

2.1.2 Market segments

The largest market for TETRA solutions is that of public safety and government, where the trend is for the deployment of nationwide TETRA networks shared by all public safety organisations for reasons of economics (sharing), autonomy of operation for routine communications and the ability to fully interoperate with other organisations during emergency situations and disasters.

The transportation market is the next fastest growing market, especially for Mass Rapid Transport systems and major Airports. Interestingly, TETRA is also used by the military for non-tactical operations, a market application not originally anticipated for TETRA.

Because TETRA has been specifically developed to serve traditional PMR users and is optimised for medium to high capacity applications by utilising Time Division Multiple Access (TDMA) technology, TETRA is also used for Public Access Mobile Radio (PAMR) applications.

Other market segments that are served by TETRA solutions include Utilities, Oil and Gas, as well as Business and Industry. Figure 1 shows the current division of TETRA market segments as of 2014 [4].

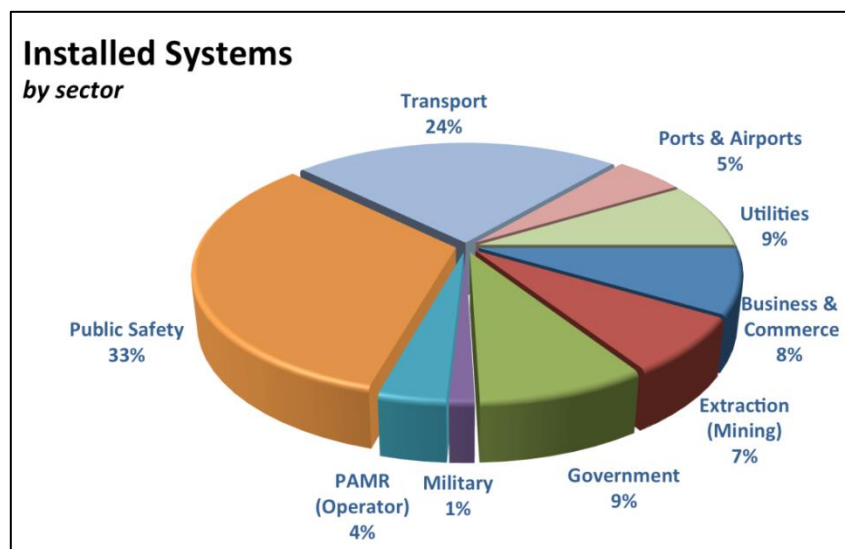


Figure 1 - Installed TETRA systems per market segment

Some other key figures on TETRA deployments include:

- Currently, over 3,150,000 critical communication professionals now use TETRA radios;
- Almost 600,000 new and replacement TETRA terminals were shipped in 2013;
- Upward trend continuing with over 4,000,000 active terminals by 2017;
- The TETRA infrastructure and System integration market is projected to be worth over €600 million in 2014;
- Services associated with the implementation and maintenance of TETRA infrastructure are expected to increase to nearly €180 million in 2014.

The TETRA infrastructure market is projected to grow at 7-8% between 2013 and 2014.

The success and market uptake of TETRA has also created a strong base of application developers who are able to provide a wide variety of applications for use with TETRA.

2.1.3 Spectrum

TETRA is a narrowband TDMA based digital radio technology that uses 25 kHz channels. Due to the stringent requirement on adjacent channel power and wideband noise, TETRA systems can be allocated channels side-by-side with analogue radio networks. Table 1 gives the different options for spectrum around the world. It is to be noted that across Europe the band 380-385 MHz paired with 390-395 MHz is the harmonised band for PPDR narrow-band systems. Out of this range, most frequencies are used for trunked mode operations (TMO) but a set of channels are reserved for direct mode operations (DMO) and air-ground-air (AGA).

Frequency band	Duplex spacing	Market
300 – 350 MHz	10 or 36 MHz	Russia
350 – 370 MHz	10 MHz	China
380 – 400 MHz	10 MHz	Europe, Asia, South America (Public Safety)
410 – 430 MHz	10 MHz	Europe, US (commercial)
450 – 500 MHz	10 MHz	Europe, US, South America, Australia (commercial)
805-870 MHz	45 MHz	US, Asia, South America (commercial)

Table 1 - Worldwide spectrum availability for TETRA

2.1.4 Evolution & Longevity

The ETSI TETRA standard will continue to evolve beyond Release 1 and Release 2 to provide additional enhancements as driven by user needs, technology innovations and other parallel standard developments. As a consequence, ETSI has no plans to develop a new technology standard for use by large traditional PMR user organisations. Similarly, other technology standards being developed and/or available outside Europe offer little or no benefit over what TETRA already provides.

This planned evolution of TETRA can be appreciated when considering that traditional PMR user organisations will always require private PMR networks because public networks cannot adequately provide the required RF coverage, Grade of Service (GoS) during busy periods, resilience and high levels of reliability. Besides these basic needs, public networks will probably not be able to provide the specialised voice services such as wide area fast call-set up all for group calls, DMO and high levels of secure encryption for voice and data. A standardised capability will be available in the mid-term but it is less certain if commercial operators would implement them unless they have a contract with an organisation requiring such specialist features.

In summary, TETRA will evolve in a similar way to GSM, which evolved from providing a basic V+D "one to one" telephony service (via GSM II+, GPRS, EDGE, etc.) to UMTS/3G supporting powerful multimedia applications and High Speed Data. Also, the focus and technology solution for Next Generation Mobile Networks (NGMN) will primarily be for public networks.

Taking these previous factors into consideration and the fact that analogue MPT 1327 trunking networks are still being deployed across the world more than 28 years after the technology was first developed, TETRA networks are expected to be available for at least another 15 years, thereby ensuring a very good return on investment for user organisations as well as manufacturers and suppliers.

2.1.5 Perspective on TETRA networks for PPDR in Europe

TETRA remains the standard-of-choice for mission critical voice and data for European PPDR organisations. Although some countries (most notably the UK) are pursuing LTE as the next step of evolution for mission-critical voice and data in the short term, most governments still expect to rely on TETRA for PPDR applications during the next 5 to 15 years. This is confirmed by recent uptake of projects for new TETRA networks (such as in Germany where the TETRA network deployment is close to being completed and Poland that will start this year) as well as replacement and upgrades of existing TETRA networks by new TETRA networks, like in The Netherlands and in Belgium.

Note that a mid-life upgrade of TETRA networks is also expected in many more countries, especially if first or second generation TETRA networks were supplied in the 2000-2008 period. New IP-based networks offer many benefits to the PPDR operator and users, including continuous support, lower operating cost and advanced functionality.

Table 2 provides a reference to the status of countrywide TETRA networks for PPDR within Europe based on intelligence gathered from multiple sources on the Internet.

Country	Network	Supplier (Infrastructure)	Base stations	Terminals	Operation
Andorra	STA	Rohill	30	1,500	2008 - 2025
Austria	TETRON	Motorola	1,300	22,000	
Belgium	ASTRID	Airbus DS	500	56,000	2000 - 2025
Denmark	SINE	Motorola	500	15,000	2007 - 2025
Finland	VIRVE	Airbus DS	1,350	55,000	
Germany	BOSNET	Airbus DS	4,500	200,000	2008 - 2025
Greece	OTE	Motorola			
Hungary	Pro-M	Airbus DS	300		
Iceland	TETRA Iceland	Motorola	150		
Ireland	TETRA Ireland	Motorola	600		
Italy	Rete Interpolizie	Selex	2,300 (planned)		
Luxembourg	Renita	Motorola	60	4,000	2013 - 2025
Netherlands	C2000	Motorola	600	35,000	2002 - 2016
Netherlands	C2000	?	600	35,000	2017 - 2025
Norway	NodNett	Motorola	2,100		
Poland	TETRA for Mol	Motorola	60	4,000	2000 - 2015
Poland	TETRA for Mol	Rohill	600	80,000	2015 - 2025
Portugal	SIRESP	Motorola	550	53,000	
Romania	STS	Motorola			
Serbia	TETRA for Mol	Motorola			
Slovenia	TETRA for Mol	Selex	70		
Spain	Various regional networks	Airbus, Rohill	150	8,000	2005 - 2025
Sweden	Rakel	Airbus DS	1,800	70,000	
United Kingdom	Airwave	Motorola	3,800	320,000	2000 - 2020

Table 2 - PPDR TETRA networks in Europe

2.2 TETRAPOL system

2.2.1 The current picture

PMR systems based on TETRAPOL standard are currently deployed in 91 networks across 35 countries and represent more than 1.85 million users. The installed base of terminals is around 800,000; one terminal being usually used by more than one user. The TETRAPOL Forum claims some 70% of the digital PMR market in Europe with 65 networks in use. Approximately 80% of the user base is in public safety and security, 15% in defence and 5% in transport and industry.

Although the TETRA standard was established after TETRAPOL, TETRA has since been adopted by the ETSI as the European standard. However, TETRAPOL delivered operational systems at an earlier date, rolling out the world's first large-scale digital PMR network in 1988 in the shape of the RUBIS system for the French National Gendarmerie at 80 MHz in VHF band (note: the first TETRA systems were not installed until 1997). Other TETRAPOL systems have been deployed in the standard UHF band around 400 MHz. Table 3 gives the TETRAPOL systems deployed in Europe [5].

Country	Network	Supplier	Base stations	Terminals	Operation
Czech Republic	PEGAS	Airbus DS	200	27,000	1995
France	RUBIS (80 MHz)	Airbus DS	500	50,000	1988
France	INPT	Airbus DS	1,500	150,000	
Liechtenstein		Airbus DS			
Slovak Republic	SITNO	Airbus DS			
Spain	SIRDEE	Airbus DS			
Switzerland	POLYCOM	Airbus DS			

Table 3 - TETRAPOL PPDR networks in Europe

TETRAPOL provides a similar set of advanced voice and data features to TETRA for public safety users, along with the same robust, secure and resilient functionality. There are multiple interoperability solutions between TETRAPOL and TETRA and even with legacy analogue systems. Today, the interoperability solution only operates in network (or relay) mode; this covers the need for cross-border/cross-network cooperation. With regards to direct mode, there is no interoperability, as this would require a dual-mode TETRAPOL-TETRA terminal and there is a very limited market for such a terminal. However, SALUS's view is that next generation PMR (broadband-based) will converge TETRAPOL and TETRA communities to a single 3GPP LTE air interface, enabling true seamless interoperability.

2.2.2 Operational trends

The new operational trends identified, that are shaping TETRAPOL's future development are presented there. These include the need for:

- End-to-end high-speed data solutions,
- New terminals,
- Applications and tactical solutions,
- Increased interoperability with other agencies, especially cross-border agencies,
- New algorithms to meet the security race.

The current economic climate also means equipment suppliers have an obligation to help PPDR end users get more out of their existing systems and find ways to reduce operational costs. The entire public safety community needs to prepare for the future, not just in terms of a new generation of base stations and terminals, but by working together to deliver a future European 4G bases PMR standard. TETRAPOL has provided a data enhancement solution (equivalent to TETRA Enhanced Data Services – TEDS), but with the growing need for data transfer in PMR, a mission critical broadband PMR solution needs to be found, while still keeping costs under control. This means more standardisation is required, along with the whole PMR community lobbying for additional harmonised spectrum to run broadband services in Europe.

2.2.3 Converged solution

In the future, broadband PPDR systems will become a true converged solution for the TETRA and TETRAPOL communities. To provide a competitive, but affordable ecosystem, the public safety community needs to:

- Harmonise spectrum;
- Establish an ‘affordable’ set of patent license fees;
- Create a terminal chipset ecosystem;
- Explore the idea of creating a converged next generation PMR European Standard with TETRA; and adapt existing PMR 400 MHz narrowband spectrum with high power devices for broadband.

Airbus DS’s new base station is an example of a step towards systems handling both narrow and broadband communications [6]. Its main advantages are:

- Integrated narrowband TETRAPOL and high-speed data solution; increased spectrum efficiency;
- Flexible frequency programming
- Operational expenses (OPEX) optimisation (70% less space is required in base station cabinets);
- Full compatibility with current networks to provide a smooth migration, ready for next generation PMR, including mission critical voice over LTE.

2.3 LTE systems

2.3.1 LTE is the global 4G cellular system

LTE is the global 4G cellular system adopted worldwide by commercial operators. At the end of September 2014, there were 331 commercial LTE networks live and running in all geographies [7]. Figure 2 gives the number of LTE networks deployed per region. In Europe, after a slow start, the adoption of LTE has significantly accelerated, with 124 commercial networks up and running. At the end of Q2-2014, there were more than 280 million LTE subscribers worldwide (with a large portion being in US).

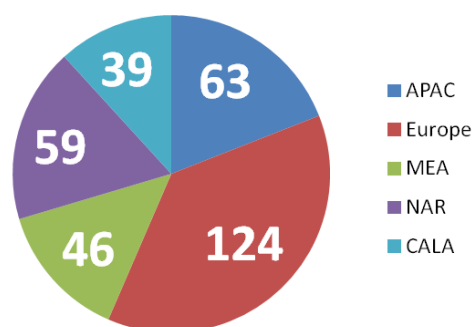


Figure 2 - Commercial LTE networks worldwide

LTE networks are deployed in a broad range of frequency bands. In Europe, most of the LTE deployments are happening in new 4G FDD bands such as 800 MHz (LTE band 20) and 2.6 GHz (LTE band 7). Many deployments are also on-going in 1,800 MHz, which was previously allocated for GSM. A few countries (in Scandinavia mainly today) are also deploying LTE at 450 MHz. Today, LTE can be deployed in a large range of spectrum bands starting from 450 MHz up to 3.8 GHz (see §5.5 in [8]).

LTE is primarily used today in commercial networks for broadband data applications (video and data) with performances much superior to 2G and 3G systems (10s of Mbps data rate and latency of few 10s of ms). A few mobile network operators (MNO) are also offering Voice over LTE (VoLTE) service now. VoLTE will get generalised in the coming years since it provides a more efficient way to transmit voice with higher quality (compared to 2G and 3G systems) and in parallel with other data services.

Some operators are also carrying out trials of enhanced multicast broadcast multimedia services over LTE (eMBMS). eMBMS can support efficiently new services that otherwise would typically consume significant amount of resources (radio and network) for instances where the same information needs to be transmitted simultaneously to multiple users in the same geographical area for a predefined duration. Such services include live/real-time streaming (of e.g. a sporting event in stadium), mobile TV or digital radio, content push and file delivery.

Moreover, with the upcoming wave of Internet of Things (IoT) and connected objects, LTE will also be used in the future for Machine Type Communications (MTC). The LTE standard is currently being improved (3GPP R13 and beyond) to optimise the support of MTC; this covers the enhancement of battery life (enhanced power save mode and efficient signalling), the reduction of terminal cost and complexity (new category of devices for narrowband operations and enhanced battery life) and enhanced coverage techniques.

2.3.2 LTE for PPDR users – Technology roadmap

LTE has been selected by major PPDR end-users associations such as the Association of Public Safety Communications Officials (APCO) and the TETRA + Critical Communications Association (TCCA) to be the follower technology of existing narrowband specialised voice-centric systems such as TETRA, TETRAPOL or P25. And, many PPDR agencies worldwide are considering options for using LTE in their operations.

LTE can be used now by PPDR agencies as a broadband data overlay complementing narrowband mission critical voice centric systems. Indeed, the superior performance of LTE compared to TETRA and TETRAPOL brings additional capabilities to support new applications such as near real-time exchange of (large amount of) information and high-quality live video streaming of a scene (Figure 3).

Today, commercial off the shelf (COTS) LTE system implements many advanced features that are of high relevance for PPDR users. These include:

- **Excellent RF performance** – LTE air interface uses state-of-the art modulation and antenna processing (MIMO) techniques over broadband channels that lead to high spectral efficiency and throughput (several 10s of Mbps depending on channel bandwidth);
- **Low latency** – LTE is an all-IP system with nearly “flat” architecture. Coupled with an air interface with sub-frame duration of 1 ms, this leads to E2E latency as low as 10 ms. This is critical when considering applications that need minimal set-up time and transmission delays.
- **E2E QoS** – LTE standard defines a comprehensive E2E QoS framework that allows differentiated and guaranteed delivery of services. LTE also implements priority and pre-

emption capabilities that can be used to further differentiate between users and applications. All the QoS attributes can be dynamically tuned to guarantee that the highest priority applications and/or group of users will get access to the radio resource under any circumstances, even when congested,

- **Built-in Security** – COTS LTE technology includes mutual authentication mechanisms between the terminals and the infrastructure to ensure that only authorized terminals can connect to a trusted infrastructure. Moreover, LTE provides over the air encryption for data (privacy) and integrity protection for the signalling information. Besides, IPsec can be optionally used between the eNodeB (eNB) and a security gateway to e.g. secure the traffic over third party backhaul.
- **Resiliency** – Being an all-IP system, each LTE eNB can be connected to multiple core network elements (namely the MME and SGW). In nominal situations, this multi-homing can be used to balance the load between the different core network elements and links. But, in the event of a failure of a core network component, the traffic to/from the eNB can be re-routed to an alternative core network element.

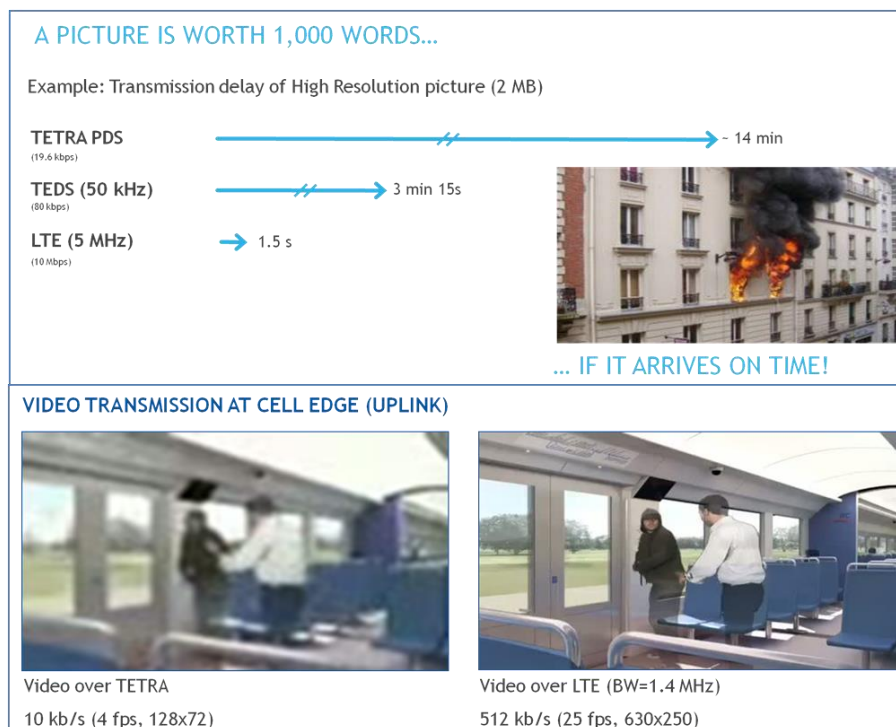


Figure 3 - Example of new capabilities for PPDR users with LTE

However, current LTE systems cannot be considered as “mission critical”. Indeed, TETRA and TETRAPOL systems include major capabilities ensuring that the system is operational and reliable under virtually any circumstance. This includes:

- The capability to operate in a scalable way with large group calls,
- The capability for terminals to communicate directly without any support from the infrastructure (in case the infrastructure is down or if a PPDR user enters in a no or limited coverage area); this is called DMO in TETRA and TETRAPOL,
- The capability for a base station to provide services in its serving area even if disconnected from the network; this is called Fallback mode in TETRA and TETRAPOL.

LTE does not provide such capabilities yet. Nevertheless, pushed by the PPDR users and suppliers, 3GPP is now developing specifications for enabling similar mission-critical capabilities on top of the current LTE standard (Figure 4).

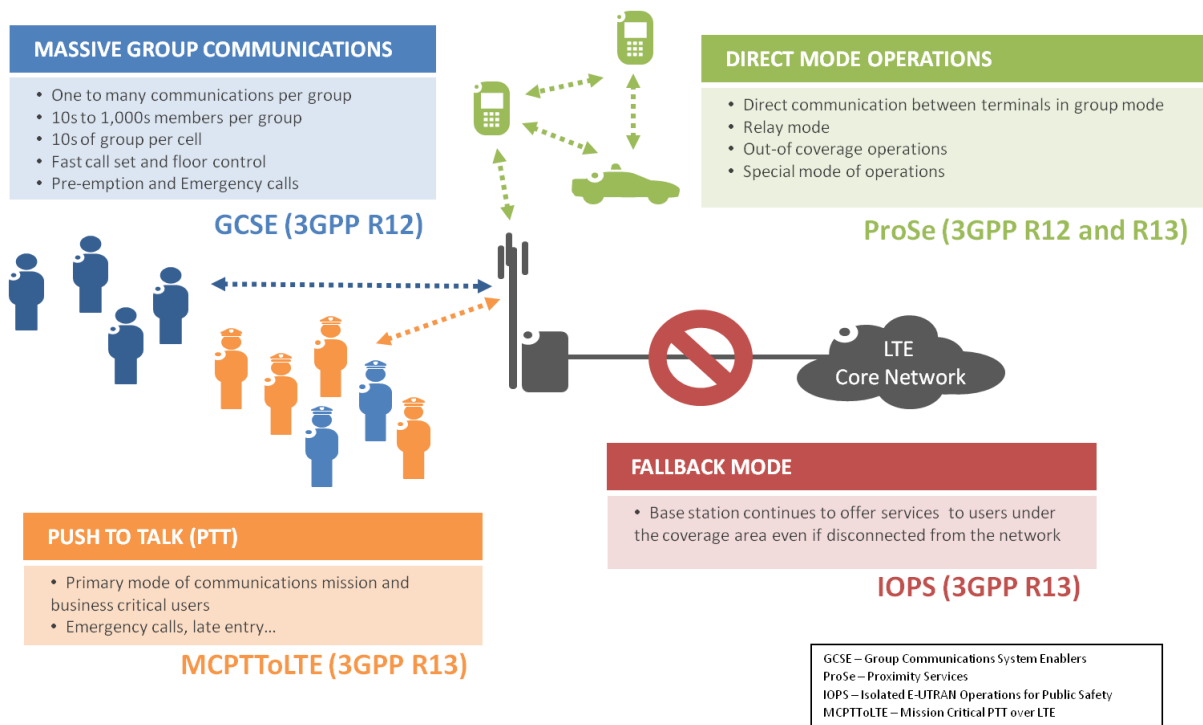


Figure 4 - Mission-Critical LTE features

First enhancements for PPDR are available in 3GPP release 12 (completion planned for Q1 2015). These include:

- **Group Communications System Enablers (GCSE, [9])** – This feature enables scalable multimedia group communications over LTE. GCSE leverages existing eMBMS specifications and enhances them by adding a new standard interface between the BM-SC (Broadcast Multicast Serving Centre) and a Group Communication Application Server (GCAS) to allow dynamic creation / modification / release of group communications over MBMS bearer,
- **Proximity-based Services (ProSe, [10])** – This feature provides first step of DMO, however in the 3GPP Release 12, ProSe is limited to discovery and device to device (D2D) communications when devices are under the coverage of a base station whereas PPDR requirements for ProSe are also when the terminals are outside the coverage area.

Second wave of enhancements will be available in 3GPP Release 13 (completion planned for Q1 2016). These include:

- **ProSe enhancements** – this will feature out of coverage D2D communications as well as relay mode for ProSe enabled terminals,
- **Isolated E-UTRAN Operations for Public Safety (IOPS, [11])** – this will mimic the existing fallback mode of TETRA and will provide service in the coverage area of a (set of) eNB to PPDR users even if this (set of) eNB is disconnected from the rest of the network,
- **Mission Critical Push to Talk (MCPTT, [12])** – PTT is a major application for PPDR users. Indeed, it provides clear voice quality from one to many PPDR users with dispatcher control. This feature will define a standard and interoperable PTT application that will leverage existing LTE standard and the additional mission critical enablers (GCSE, ProSe, IOPS). It is to be noted that it has been recently agreed that MCPTT

would finally be standardized by 3GPP; a specific working group has been recently created for that purpose (SA6 group).

Based on the current 3GPP calendar and on the industry average to turn a standard into a product (18 months to 24 months), it is envisaged that first mission-critical LTE systems will be available from 2018. At that time, LTE will be capable of providing similar level of resiliency and functionality than current specialized PPDR narrowband systems.

After 3GPP R13, additional enhancements will be defined. At the time of writing this report, the definition of scope of work of 3GPP R14 has not started yet but some early proposals express the interest to standardize additional multimedia group communications over LTE (video based, messaging based...). In the final version of the report, an update on the standardisation activities will be provided.

It is also to be noted that some Chinese suppliers (Huawei and ZTE) are offering today proprietary solution with a subset of the features (especially the PTT). However, these solutions are not in-line with the 3GPP standard and are book-ended solutions with vendor lock-in for terminals, infrastructure and part of the applications.

2.3.3 Spectrum for PPDR

Although LTE has been recognised as the follower technology for TETRA and TETRAPOL, availability of dedicated spectrum for broadband PPDR remains a blocking issue today in Europe. Governments usually see high revenues being generated by selling spectrum to commercial mobile operators who in turn use the spectrum to sell services that generate economic growth and tax revenues. PPDR organisations are seen as incurring important cost to governments and are demanding significant amount of spectrum for a small but important community. This point is currently under debate at European regulatory level. But indeed, without dedicated spectrum, no dedicated network can be deployed.

USA has been the first country to allocate dedicated spectrum for PPDR. The 5+5 MHz previously allocated has been extended to 10+10 MHz in 700 MHz band (so called band 14). Canada has also decided to allocate 5+5 MHz in the same band.

Outside North America, some countries have allocated (or are about to allocate) dedicated spectrum for PPDR:

- In Latin America, Brazil (5+5 MHz) and Chile (10+10 MHz) are allocating dedicated spectrum in the 700 MHz band 28,
- In South Korea, 10+10 MHz has recently be allocated in 700 MHz band 28,
- In Australia, 5+5 MHz will be allocated in the range of 800/900 MHz,
- In Middle East, Qatar has already deployed a broadband PPDR system at 800 MHz (band 20) but the other Gulf countries are considering to use the future 700 MHz band 28 for PPDR.

In Europe, the situation is today under discussion. In preparation for the World Radio Conference 2015 (WRC-15), CEPT is discussing options for broadband PPDR either in the 400 MHz range (410-430 MHz or 450-470 MHz) and/or in the new 700 MHz spectrum that will be allocated out of the second digital dividend. Coexistence studies are being conducted and different options are being studied with the aim to reach a consensus within the PPDR community but also with other major stakeholders such as the regulators, the broadcasters and the mobile operators. For the time being, the only member state that took a decision is Spain that announced that they will make available 5+5 MHz of spectrum in the 450-470 MHz band. In the final version of the report, further insight on this topic will be provided based on the outcome of WRC-15.

It is however to be noted that 400 MHz range is usually heavily utilised and therefore significant re-farming will be required to make enough spectrum available for LTE. This might be challenging in some European countries preventing any European harmonised solution in this band. However, since an ecosystem is developing in the 450-470 MHz band also for commercial network, this remains an interesting option. 700MHz may be seen as a better option for a European wide PPDR allocation although many regulators are opposed to having a European dedicated band. Current trend is that regulators favour a flexible arrangement where each nation decides whether to allocate (or not) 700MHz for PPDR and if so how much spectrum to allocate and the location of the spectrum (e.g. from the MFCN bands, guard bands, duplex gap or a mixture of these) within the band. Some countries (like France) are favouring a mix approach at 700 MHz and 450 MHz to benefit from best of both options (higher capacity at 700 MHz and longer range at 450 MHz due to the bands better propagation characteristics plus the possibility to use higher power devices that are not possible in 700 MHz).

2.4 Wi-Fi Systems

In Wireless Networking, most of the Wi-Fi systems work in two different modes: Infrastructure and Ad-Hoc. The two following section discuss both modes.

2.4.1 Infrastructure mode

In the infrastructure mode the devices are not communicating directly but can communicate through an access point (AP) which is usually a wireless router. Infrastructure mode requires a central AP that all devices connect to and this AP is also connected to the Internet or Intranet. The infrastructure mode of these networks is ideal when setting up a more permanent network [13]. Wireless routers operate as access points and generally have higher-power wireless radios and efficient antennas so they can cover a wider area (although they have to keep the effective radiated power within the maximum power allowed by the regulator). In comparison with the Ad-Hoc networks, infrastructure networks have the advantages of centralized security management, scalability and improved reach but the additional cost of APs is the only disadvantage of infrastructure wireless networks.

Global public Wi-Fi hotspot numbers are set to grow from 1.3 million in 2011, to 5.8 million by 2015, marking a 350% increase, according to research published by the Wireless Broadband Alliance (WBA) [14]. The growth in Wi-Fi hotspots will primarily be in three types of location: wide-area outdoor hot-zones, such as parks; local-area outdoor hot-zones, such as popular tourist attractions, and transport hubs, such as airports and main train stations (see Figure 5). In addition, the global Wi-Fi market is forecast to grow to \$26.19 billion by 2019. In terms of regions, North America is expected to be the biggest market in terms of market size, while Asia pacific and Latin America are expected to experience increased market traction during the forecast period. Currently, over 5,000 hotspots are estimated in over 21 European countries [14].

By Venue Type (hotspots only)	2013	2014	2015	2016	2017	2018
Airports	5,915	6,018	6,118	6,212	6,306	6,386
Hotels	321,416	334,359	347,894	362,050	376,860	397,905
Cates, Restaurants	2,856,770	3,077,392	3,323,954	3,600,154	3,910,288	4,259,351
Retail & Outdoor	3,844,637	4,149,784	4,488,903	4,866,929	5,289,653	5,763,907
Municipal Outdoor	15,794	15,794	20,733	31,196	48,170	77,512
Airplanes	3,273	3,415	4,743	7,002	10,346	15,794
Trains	1,196	1,503	1,815	2,610	3,693	6,508
Other	116,163	677,928	883,875	1,135,392	1,435,277	1,702,034
Total	7,165,164	8,266,193	9,078,035	10,011,545	11,080,593	12,229,397

Figure 5 - Wi-Fi Hot-Spots by venue type 2013-2018 [14]

Most of the existing operating 2.4 GHz hotspots employ multiple APs with seamless roaming to counterbalance the limited range of each generic Wi-Fi AP due to channel characteristics and

respective attenuation phenomena, as well as equivalent isotropic radiated power (EIRP) limitations imposed by EU regulations at 100 mW. At 1 meter from the transmitter, the reference path loss is up to 40 dB and shadow fading and scattering both contribute to the signal attenuation. Expected values of 10-12 dB for shadow depth should be expected in a typical dense urban environment. These values can increase significantly in an indoor propagation topology, such as the aforementioned public commercial topologies where hotspots operate. In addition, body shadowing also affects signal propagation [15].

The bit rate of the 802.11b/g networks is also limited. In everyday realistic scenarios, data rates are estimated to around 10 to 12 Mbps to be shared by all users connected to the AP. In cases of metropolitan area networks, the possible exploitation of 802.11a “backbone” links operating at 5.8 GHz could be a useful potential infrastructure for PPDR services. In addition, the 802.11n protocol delivers higher bit-rates with an increased bandwidth of 40 MHz and a bit rate that can reach 50-60 Mbps in realistic urban channel conditions, with a target of 100 Mbps [16].

Future enhancements of Wi-Fi for wide area networks are towards larger and better broadband networks for streaming services and real-time applications. The gigabit 802.11ac extension runs in the 5 GHz band, and enables devices to achieve real world peak speeds of over 400 Mbps. In addition, 802.11ad designed to increase speeds (to theoretical peaks of over 3 Gbps) and capacity via wide channels and MIMO techniques, is expected to operate in the unlicensed 60 GHz band, where oxygen absorption-losses create a great potential for highly-directive communications. 802.11aj will adapt 11ad for the 45 GHz band, used in China in particular, whereas interesting solutions are underway for Wi-Fi in TV White space sub-1 GHz frequencies [14].

Public safety applications can be supported by these networks. Examples are [17]:

- Real-time Broadcast of Critical Alerts for time-sensitive information for example weather, theft and general crime alerts in addition to Emergency Broadcast System bulletins,
- Direct mobile access for real-time queries/updates of databases maintained by national and law agencies such as criminal records,
- Direct mobile access to critical information while on route to an accident or other emergency incident. This includes chemical manufacturing data or hazardous materials, inspection records, GIS (geographic information) and street maps. Moreover, up-to-date traffic reports could assist PPDR personnel to optimize responsiveness by choosing the fastest if not the most direct route,
- In mobile access applications, public safety workers can do a variety of functions in the field that formerly required a trip back to the police station or hospital, including creation and filing the incidents and other activities such as emailing and web-based research, etc. This increases the visibility of the public safety presence in the community.

At the scene of an incident, the capabilities of Wi-Fi bring attention to the opportunistic and secure use of WLANs as an alternative method of public safety communications either from an infrastructure perspective or from an ad-hoc mode.

2.4.2 Ad-hoc mode

PPDR communications need to be operational under all conditions. Ubiquitous coverage, resilience and hot-spot capacity are major challenges that need special attention. Wireless Local Area Network (WLAN) ad-hoc networks can aid in addressing these challenges.

The nature of ad-hoc networks is that capacity and coverage of the network is provided by the same equipment that requires capacity and coverage. It is a form of mutual aid, fitting to group operation, as is typical for PPDR organisations, in particular in temporary protection or disaster relief scenarios. The communication facility of the ad-hoc network is however always limited to

the ad-hoc network as such. So a stand-alone ad-hoc network can only provide communication facilities for isolated group operation.

Combining ad-hoc network functionality with infrastructure based backhaul however creates a solution where the ad-hoc network serves multiple purposes. First of all, it provides a local network for all forms of local communication. As communication remains local, this traffic load does not load the infrastructure, which is expected to be heavily loaded or even overloaded in the golden hour of PPDR operations. Secondly, as the users are close together, the radio conditions of the direct path between users is typically much better than for the path between user and infrastructure. Using adaptive modulation and coding schemes, the radio load of such communication is even further limited. Thirdly, infrastructure-based coverage may not be ubiquitous due to being at difficult locations (e.g. underground, hilly terrain, off-site, etc) or due to network failure. In such case the ad-hoc network does provide coverage or coverage extension. Finally, as WLAN operates in licence exempt frequency bands, ad-hoc WLAN networks can be deployed without prior licensing or planning. So ad-hoc networks are ideal when the situation requires improvisation. However, using license exempt spectrum might be a challenge in cities (but not so much in rural and remote areas) due to potential sources of interferences from surrounding systems sharing the same spectrum.

The concept of mobile ad-hoc networking technology finds its origin in the military domain. In particular the PRNET from DARPA [18] is considered the foundation for Wireless Ad-hoc NETwork (WANET) solutions [19]. Already from the start of the standardization IEEE 802.11 protocols supports ad-hoc networking. The protocol contain the option for IBSS (Independent Basic Service Set) defining an infrastructure-less operation.

On top of this basis the IEEE 802.11s [20] extension defines an architecture and protocol that supports both broadcast/multicast and unicast delivery using “radio-aware metrics over self-configuring multi-hop topologies”. The standard provides a framework, whereas the detailed definition of metrics is up to developers. IEEE 802.11s was approved in 2011.

IEEE 802.11 defines the physical (PHY) and medium access control (MAC) layers. The Mobile Ad-hoc NETwork (MANET) however requires in addition networking functionality, which is outside of the scope of IEEE 802.11. IEEE802.11s supports Hybrid Wireless Mesh Protocol (HWMP) by default. HWMP focuses on fixed mesh-networks and is therefore not suitable for the MANET.

The two most popular ad-hoc routing protocols that are also supported by IEEE 802.11s are Optimized Link State Routing Protocol (OLSR) and Better Approach To Mobile Adhoc Networking (B.A.T.M.A.N.).

The OLSR is a link-state protocol that creates and maintains the network topology using 2-hop neighbour information. Based on this information it selects/elects a set of Multi-Point Relays (MPR) that ensures connectivity of the network. OLSR is a proactive protocol, which implies that the network continuously builds and maintains the topology. OLSRV2 [21] extends the solutions creating a more flexible and modular design using shared components as the Neighbourhood Discovery Protocol (NHDP). These components are (to become) common among next generation IETF MANET protocols. OLSR works at layer 3.

B.A.T.M.A.N. [22] is a distance vector protocol, selecting the neighbour with the lowest hop-count for forwarding to the destination. In order to build and maintain the routes B.A.T.M.A.N. repeatedly sends broadcasts, so that all nodes remain visible. B.A.T.M.A.N. operates at layer 2, which implies that all ad-hoc nodes act as a distributed switch. B.A.T.M.A.N. is actively maintained and is part of the Linux kernel.

Of these two approaches OLSR seems to be the most promising for two reasons. First OLSR acts at layer 3. Resulting, each node in the MANET is a separate subnet. This matches the architecture of (mobile) PPDR networks, where terminals are also subnets on their own. Secondly, OLSR is used and supported by the military domain, i.e. by a sector with similar usage.

3 POSSIBLE FUTURE MODE OF OPERATIONS

This section explains the different models of how PPDR users can get broadband services and discusses the merits of the models.

3.1 Description of different possible models

3.1.1 Broadband services from Mobile Network Operators

PPDR organisations may get broadband services from one or several mobile network operators (MNO) that have already deployed (or are going to deploy) a LTE network in the country. From a high level perspective, this approach may have several advantages such as:

- **Limited investment** – The PPDR organisation does not have to invest in a new radio network infrastructure. Investments are limited to terminals, new applications (might include security aspects), gateway to interconnect PPDR users in the legacy networks to PPDR users on the MNO network. Service subscription fees will also have to be paid to the MNO.
- **No need for dedicated spectrum** – As mentioned earlier, the access to dedicated broadband spectrum is today a major hurdle in Europe. Getting broadband services from a MNO will overcome this major challenge.
- **Quick timing** – Broadband services, if already deployed in the country by an MNO, can be immediately available in the service area of the MNO.
- **Large ecosystem** – Since the service will be accessed through a MNO on commercial spectrum, PPDR users will have access to a broad range of COTS terminals.

However, such approach also has major drawbacks that may not be critical in the early phases of use of LTE for non-mission critical applications but will certainly become major blocking points when broadband mission-critical applications are required. For instance, those blocking points might be:

- **No or limited control on access / use of radio resources** – When getting services from a MNO, PPDR users will be contending with the bulk of commercial users (that are 50 to 100 times more numerous than PPDR users) to access to the resource and may not have access to that resource when absolutely needed. This may be critical especially in emergency situations. Indeed, it is well known that during major events, commercial networks tend to be saturated.
- **Non homogeneous coverage** (capacity driven availability vs. coverage availability) – Commercial networks are deployed according to the population density for maximising the return on investment. In areas where the population density is low, access to wireless broadband service is usually not possible. In that case, access to the broadband services over 4G might be limited in the short term to some areas only (main cities) and eventually rely on commercial 3G or 2G in the other areas (see §3.1.1.4 for more details on 4G availability across Europe).
- **Limited resiliency** – Commercial networks are usually not designed to be tolerant to multiple failures or to extreme situations where power is not available to the radio site for long duration. PPDR users need their system to operate under any circumstances and current PPDR networks are usually deployed with multiple redundancy mechanisms at different levels in the network architecture (base station, backhaul, switches...) and the radio sites are usually hardened with power back-up of a few days in some cases compared to a few hours for a commercial network.

- **Lack of support of future LTE Public Safety features** – Looking forward, the new LTE Public Safety being specified in 3GPP release 12 and beyond (such as GCSE, ProSe, IOPS, MCPTT...) will be essential for efficient operation of PPDR applications over LTE. However, these features being dedicated to PPDR applications only, it is still to be seen whether many MNOs will deploy them when available or not.
- **Lack of ruggedized terminals** – this will depend on whether the MNO model is adopted by enough PPDR users to create a market of sufficient size for the terminal manufacturers.

The following sub-sections will review the different models that PPDR organisations can use to get broadband services from a MNO. Besides, since these models rely heavily on the presence of radio coverage of the MNO, an additional section will give some examples of 3G/4G coverage (population and geographical area) from few selected member states.

3.1.1.1 Standard MNO 3G/4G data plan subscription

The simplest way for a PPDR organisation to get access to broadband wireless services is to get a broadband mobile data subscription from a commercial operator. The PPDR organisation will pay a monthly fee per subscriber to the commercial operator based on the agreed commercial contract. Many PPDR organisations do use today this model to get access to non-mission critical data applications over 2G/3G. For instance, the UK police make use of Blackberry terminals and specific low bandwidth applications for accessing or updating records on the go allowing them to spend more time out in the street instead of spending time in paper work at the police station. However, supporting new bandwidth demanding applications such as video or high definition picture transmission will require the PPDR organisation to subscribe and get access to 4G services.

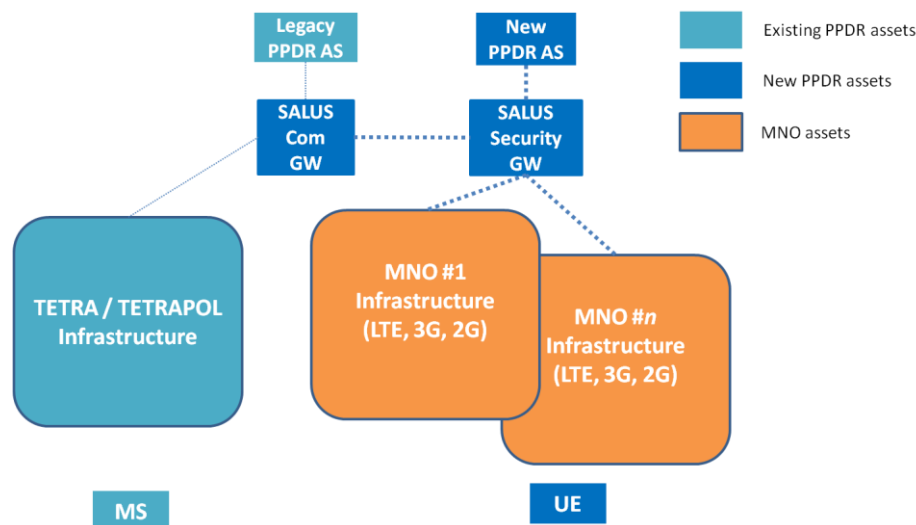


Figure 6 - High level architecture of the MNO model

This approach is probably the one requiring the lowest level of investment. In terms of capital expenditures (CAPEX), the PPDR organisation needs to invest in LTE terminals, end-user devices (camera, sensors...), applications (client and server sides). Optionally, the PPDR organisation may also need to invest in a communication gateway ('SALUS communication Gateway') to enable communications between PPDR users using a legacy terminal and PPDR users connected on the LTE network and a security solution (such as over the top E2E VPN) to ensure additional privacy of the communications over the commercial network (Figure 6). In terms of operational expenditures (OPEX), this will be limited to monthly subscriptions (to one or more MNOs) and to operations and maintenance fees of the new equipments being deployed (new applications, SALUS communications and security gateways). In this model, the subscribers and the terminals are managed by the MNO.

A summary of the CAPEX and OPEX items for the PPDR organisations are summarized in Table 4.

Standard MNO data plan	CAPEX	OPEX
Terminals	COTS terminals (tablets and smartphones, USB dongles) Ruggedized terminals (vehicular routers, rugged tablets and smartphones...)	
Network	One-off set up fee per subscription	Subscription fees per subscriber
Gateways	SALUS Communication Gateway SALUS Security Gateway	Operation and Maintenance of the Gateways (HW and SW)
Applications	End-user device (e.g. camera, sensor...) Application software and servers (e.g. video management system...)	Maintenance of application servers (HW and SW)

Table 4 - Investment summary for the Standard Data Subscription Model

This model, although simple and straightforward, has a number of major drawbacks and cannot realistically support mission critical applications:

- **No or very limited guarantee** – Access to the broadband service is not guaranteed. The PPDR users are using the same network(s) as standard users. Especially, in case of major events where networks tend to become congested, this creates a significant issue for PPDR users. If agreed (probably with a higher fee) with the MNO, PPDR users may eventually have higher level of priority however, if end-to-end virtual private network (E2E VPN) is deployed this may mask the attributes of the IP packets transmitted over the LTE network and the LTE system will not be able to filter the packets and process them according to their QoS profile. An alternative solution for this is to have multiple E2E VPN attached to different APN (one per type of QoS to be supported [23]). It is to be noted that MNO may implement Access Class Barring to limit the outgoing calls from standard users in case of a crisis situation.
- **Limited availability** – services will be only available where the MNO has already deployed a 4G infrastructure, which is today and probably for the years to come unlikely to represent a significant geographical portion of a country (see 3.1.1.4). Besides, even if 3G coverage is more ubiquitous, 3G speeds are not compatible with the most bandwidth demanding PPDR applications.
- **Recurring costs** – the traffic profile from PPDR users might be different from regular users and might incur high recurring costs especially if the traffic to be conveyed is high (for instance a camera transmitting at 2 Mbps 4 hours a day would consume 110 GB per month) and if the number of subscriptions is high. This recurring cost may represent few m€ to 100 m€ per year and cumulated over a period of 10 years must 10s to 100s of m€ (Figure 7).

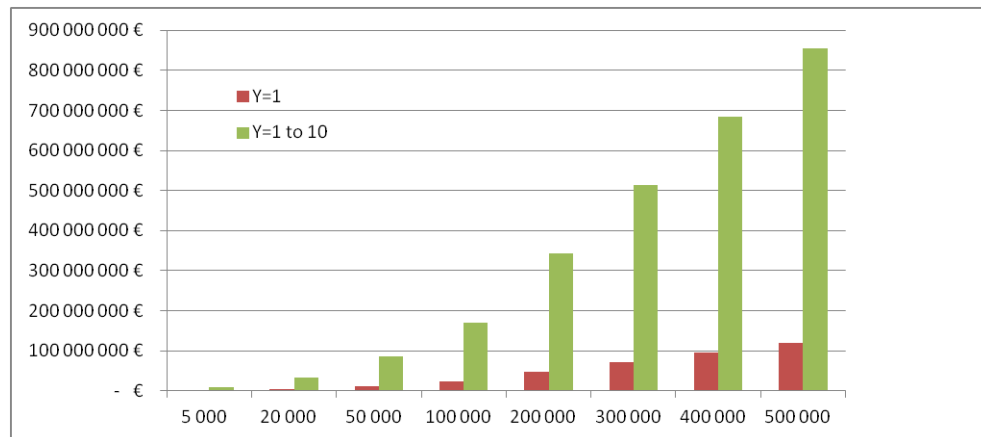


Figure 7 - Example of recurring cost for one year (Y=1) and cumulated over 10 years (Y = 1 to 10) as a function of the PPDR subscribers [assumptions, unlimited data plan at 20€ / month subscription fee with 5% yearly discount]

3.1.1.2 PPDR MVNO – light

Another MNO access based model to have access to broadband services is to set up a light mobile virtual network operator (MVNO). This model is called the light PPDR MVNO model in the document. In this model, three business models are possible:

- Every single PPDR organisation establishes its owns light PPDR MVNO solution (called light MVNO PPDR A),
- One leading PPDR organisation establishes a unified light PPDR MVNO solution for all PPDR organisations (called light MVNO PPDR B),
- A trusted entity establishes a light PPDR MVNO and provides broadband services to all in country PPDR organisations (light MVNO PPDR C).

The first business model is in principle the less appealing since every PPDR organisation will have to invest in additional network infrastructure and in associated operations and maintenance. Besides, in this case, the negotiation with the MNO(s) for bulk access to network resources will be tougher since the number of users will be lower (less volume). The second and the third business model are very similar, since there is only one entity investing in the additional network equipment and negotiating bulk access to the network for all the PPDR users. However, the third model might be appealing to outsource the telecom operations to a trusted entity rather than investing in training PPDR personnel on network operations of new technologies.

Compared with the standard MNO data plan model, the light PPDR MVNO operator manages the subscribers and the devices for the end-users, which gives better flexibility and security. The additional investments would consist in acquiring the 4G subscriber database (home subscriber server, HSS), a signalling gateway to interconnect the HSS to the MNO network(s) (the Diameter Edge Agent, DEA), a mobile devices and applications management system and the SIM cards. If the PPDR MVNO has a Service Level Agreement (SLA) with multiple MNOs, it may also need to invest in a mobility solution (SALUS Mobility GW) ensuring that PPDR users are always best connected to the network that gives the better signal quality and/or the best throughput and/or the best QoS and/or the best pricing scheme (Figure 8).

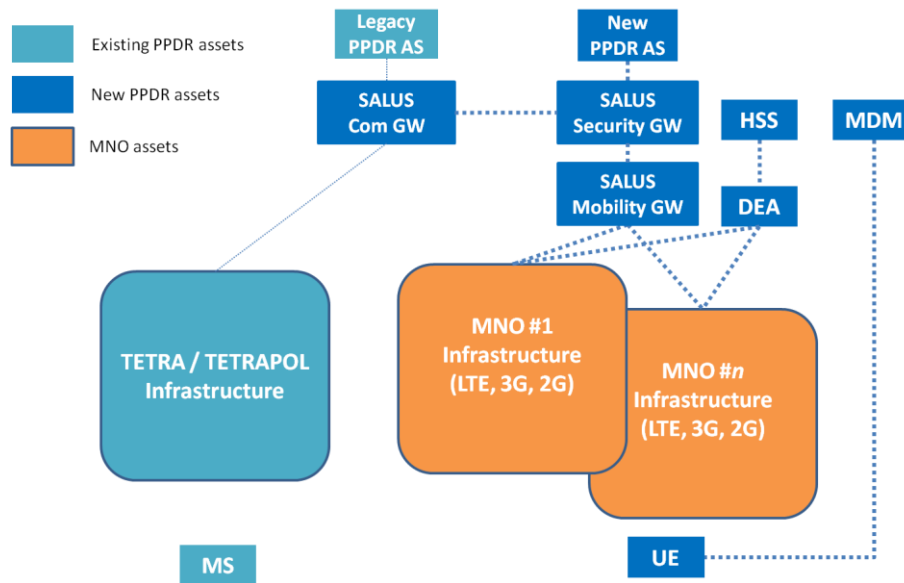


Figure 8 - High level simplified architecture for light PPDR MVNO

The following table summarises the CAPEX and OPEX items for the different business models when the PPDR users is the one managing the light MVNO (Table 5) and when the PPDR user get services from a third party light MVNO provider (Table 6).

Light PPDR MVNO A	CAPEX	OPEX
Terminals	COTS terminals Ruggedized terminals MDM platform	Operation and Maintenance of the MDM (HW and SW)
Network	HSS/DEA	Bulk subscription fees per MNO Operation and Maintenance of the HSS/DEA (HW and SW)
Gateways	SALUS Communication Gateway SALUS Security Gateway SALUS Mobility Gateway	Operation and Maintenance of the Gateways (HW and SW)
Applications	End-user device (e.g. camera, sensor...) Application software and servers (e.g. video management system...)	Maintenance of application servers (HW and SW)

Table 5 - CAPEX and OPEX summary for light PPDR MVNO A

Compared to the standard MNO data plan approach, this model has the same drawbacks. However, if the PPDR MVNO has agreement with multiple operators, it can benefit from always best connection among the different MNO. But it is to be noted that to benefit from connectivity from multiple MNOs, either national roaming needs to be allowed (which is not the case in most European countries) or either the PPDR organisation makes use or establishes itself as an international MVNO. And even then, the mobility between MNOs might not be seamless and complex to manage.

Light PPDR MVNO B or C	PPDR MVNO provider		PPDR MVNO user	
	CAPEX	OPEX	CAPEX	OPEX
Terminals	MDM	Operation and Maintenance of the MDM (HW and SW)	COTS terminals Ruggedized terminals	
Network	HSS/DEA	Bulk subscription fees per MNO Operation and Maintenance of the HSS/DEA (HW and SW)		Monthly (or yearly) fee for fleet of PPDR users to PPDR MVNO provider
Gateways	SALUS Communication Gateway SALUS Security Gateway SALUS Mobility Gateway	Operation and Maintenance of the Gateways (HW and SW)	Additional security solution (option)	Maintenance of additional security solution
Applications			End-user devices Application software and servers	Maintenance of application servers (HW + SW)

Table 6 - CAPEX and OPEX summary for light MVNO models B and C

3.1.1.3 PPDR MVNO - Full

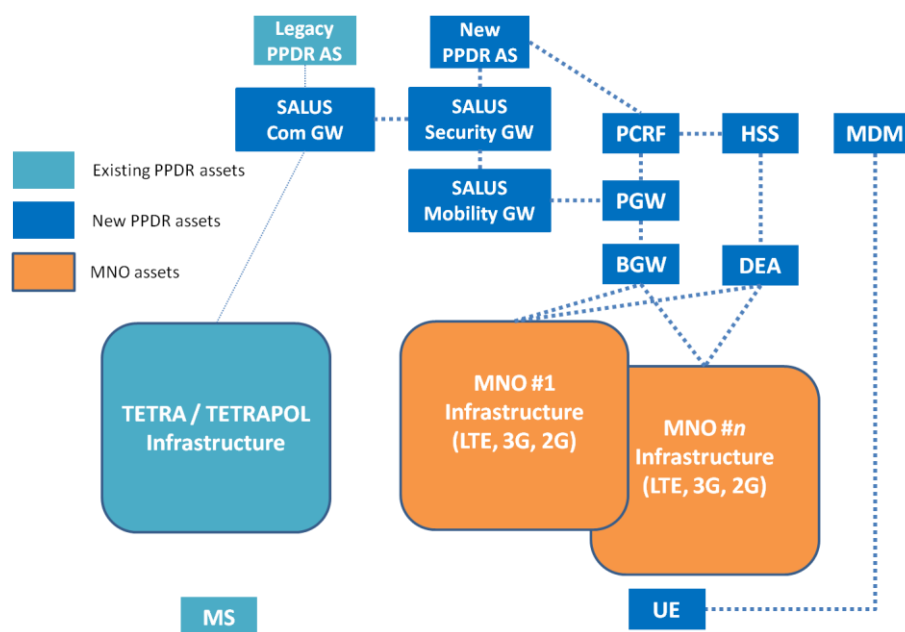


Figure 9 - Simplified High Level Full PPDR MVNO architecture

The Full PPDR MVNO model is an extension of the light PPDR MVNO model. In that case, the PPDR MVNO provider also invests in additional LTE core network equipment (PGW and PCRF)

and a Border Gateway (BGW) connecting to the IP exchange (IPX) network interconnecting LTE mobile networks. Compared with the light PPDR MVNO model, this gives additional control on services and on end-to-end QoS over the LTE access network. Indeed, the PCRF deployed in the full PPDR MVNO will enforce the E2E QoS from the PGW that is connected to the MNO access network (Figure 9).

The business models are basically the same as for the light PPDR MVNO (in the following, the identification of the model names will follow the same logic as in §3.1.1.2 replacing “light” by “full”); however, the PPDR MVNO provider may also get the infrastructure services from a mobile virtual network enabler (MVNE). This latter model is the model used in Belgium by ASTRID, the government entity operating the professional services for PMR users in Belgium (PPDR, Transport, Utilities...) [24].

The following tables summarise the CAPEX and OPEX items for the different business models when the PPDR users is the one managing the Full PPDR MVNO (Table 7) and when the PPDR user get services from a third party Full PPDR MVNO provider (Table 8).

Full PPDR MVNO A	CAPEX	OPEX
Terminals	COTS terminals Ruggedized terminals MDM platform	Operation and Maintenance of the MDM (HW and SW)
Network	HSS/DEA PCRF PGW/BGW	Bulk subscription fees per MNO Operation and Maintenance of the network equipment (HW and SW)
Gateways	SALUS Communication Gateway SALUS Security Gateway SALUS Mobility Gateway	Operation and Maintenance of the Gateways (HW and SW)
Applications	End-user device (e.g. camera, sensor...) Application software and servers (e.g. video management system...)	Maintenance of application servers (HW and SW)

Table 7 - CAPEX and OPEX summary for Full PPDR MVNO A

Compared to the light PPDR MVNO model, the Full PPDR MVNO model provides more control on E2E QoS for the PPDR applications in the coverage area of the MNOs. However, it still suffers from the other drawbacks. Another interesting point of this model is that it can also be seen as a relevant first step towards dedicated broadband PPDR. Indeed, all the LTE core components that would be deployed by the Full PPDR MVNO provider can also be used in a later step to be used as LTE core network components for a dedicated PPDR LTE access network.

As already mentioned, ASTRID is following this approach to provide “non mission critical data” services to its subscribers. They rely on a MVNE that ensures the connectivity to the different Belgian mobile operator and also roaming to neighbouring countries. Another example of this model is the Emergency Services Mobile Communications Program (ESMCP) by the UK Home Office. The objective in that case is quite ambitious; completely replacing the TETRA network managed by Airwave by an LTE only network relying on a MNO network and an Emergency Services provider (i.e. a Full PPDR MVNO provider). This program is in tender stage at the time of writing this report.

Full PPDR MVNO B or C	PPDR MVNO provider		PPDR MVNO user	
	CAPEX	OPEX	CAPEX	OPEX
Terminals	MDM	Operation and Maintenance of the MDM (HW and SW)	COTS terminals Ruggedized terminals	
Network	HSS/DEA PCRF PGW/BGW	Bulk subscription fees per MNO Operation and Maintenance of the network equipment (HW and SW)		Monthly (or yearly) fee for fleet of PPDR users to PPDR MVNO provider
Gateways	SALUS Communication Gateway SALUS Security Gateway SALUS Mobility Gateway	Operation and Maintenance of the Gateways (HW and SW)	Additional security solution (option)	Maintenance of additional security solution
Applications			End-user devices Application software and servers	Maintenance of application servers (HW and SW)

Table 8 - CAPEX and OPEX summary for Full MVNO models B and C

Table 9 gives an idea of the pricing scheme provided by ASTRID to the end users in Belgium; it is based on fleet. There a monthly fee per fleet with a maximum data amount per fleet plus a monthly fee of 10€ per month per activated SIM ([25]).

Monthly Volume	Maximum number of users per fleet	Monthly fee per fleet	Monthly fee per activated SIM	Set up fee per SIM
5 GB	10	250€	10€	10 €
10 GB	30	500€		
15 GB	50	750€		
25 GB	100	1,250€		
40 GB	250	2,000€		

Table 9 - ASTRID pricing scheme after 1st July 2015 ([25])

For larger fleet, no indication of pricing is provided. Extrapolating these values to larger number of PPDR users would actually lead to large OPEX for the PPDR users.

3.1.1.4 Are 4G signals from MNO available anywhere?

LTE networks are being currently deployed by most MNOs in Europe. However, as explained before, in most European countries, LTE deployments have clearly focused so far on urban areas except for Sweden, Estonia, Germany, Luxembourg and Slovenia. The European

Commission maintains a scoreboard for broadband market that gives 4G penetration (% of population) in the different member states including penetration in rural area. It definitely shows, as of today, LTE coverage is not widely available (Figure 10).

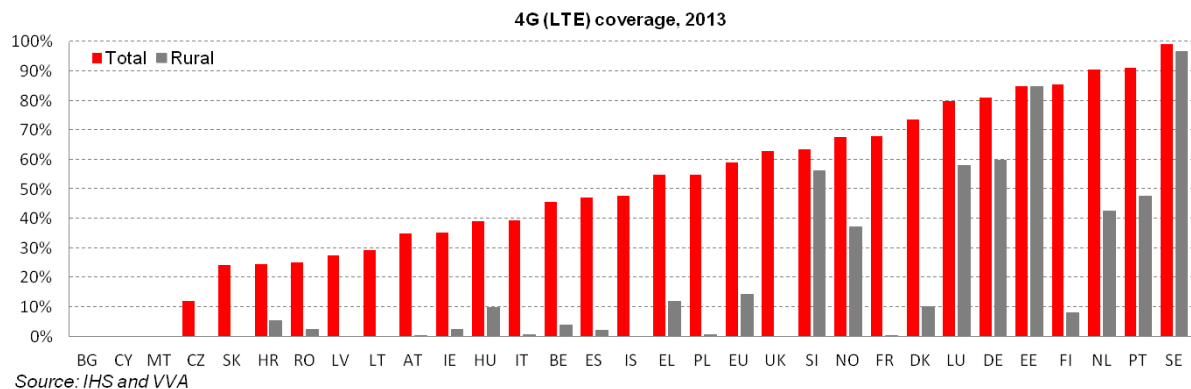


Figure 10 - 4G penetration in the member states in 2013 ([26])

The picture looks even worse when looking at the statistics of geographical coverage vs. population coverage. Below are a few examples of some member states 4G deployment coverage statistics that illustrate that.

In France, according to a report from the French regulator (ARCEP), although some operators provide 4G services to 70% of the population, this actually represents only 22% of the geographical coverage. In comparison, 3G covers nearly 99% of the population and covers almost 90% of the country [27]. It is to be noted that based on regulatory objectives, French commercial operators have a target to cover 75% of the French metropolitan territory by October 2023, 98% of the territory by January 2024 and 99.8% of the territory by January 2027.

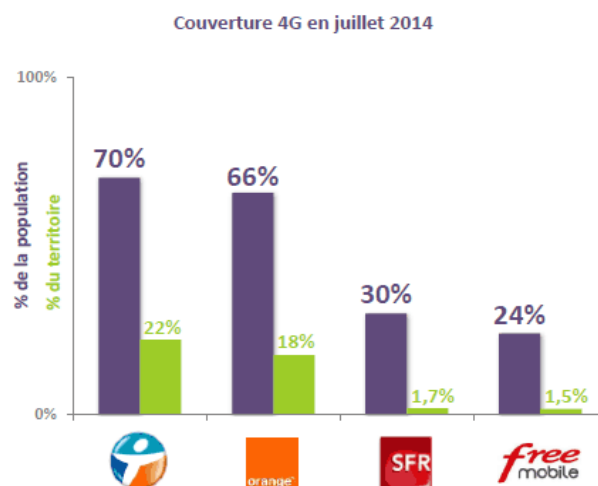


Figure 11 - 4G coverage in France, July 2014 ([27])

In UK, Ofcom has recently published statistics on 4G coverage. It shows that although 72% of the premises are covered by at least 1 operator, there is 77% of the territory where there is no 4G signal available. It also shows that 25% of the motorways and 63% of roads are not covered by 4G (Figure 12). It is to be noted that current spectrum award for LTE include coverage obligations based on population (e.g. 98% of UK population and 95% of each England, Scotland, Wales, and Ireland by end 2017) and not landmass.

	Complete 'not-spots'	Partial 'not-spots'	Covered by Vodafone, O2 and EE
Outdoor coverage			
Premises	28%	37%	35%
Geographic	77%	17%	5%
National roads coverage			
Motorways	25%	47%	28%
A & B Roads	63%	25%	12%
Indoor/In-car coverage			
Premises	37%	34%	30%
Motorways	36%	43%	21%
A & B Roads	71%	20%	9%

Source: Ofcom analysis of MNO data

Figure 12 - UK 4G mobile network coverage, June 2014 ([28])

In the final version of the report, additional statistics (percentage of population and land covered and regulatory objectives and timing) from multiple member states will be provided.

3.1.1.5 The role of Wi-Fi in getting services from MNO

Wi-Fi services via MNO networks can enhance the MNO business model. The expansion of Wi-Fi networks via LTE infrastructure can enhance mobility and interoperability as well as broadband services especially in areas where wired infrastructure may suffer and thus provide generic connectivity. In cases where there is need for access in remote, out band elements [29], MNO infrastructure can provide connectivity and thus provide the platform for Wi-Fi services and thus enhance its business model.

Moreover, as part of the extension of broadband connectivity in rural areas the so-called “white areas” [30], where dated wired infrastructure and irregular terrain conditions do not allow for fibre optics and/or broadband cabling, MNO deployment can also provide Wi-Fi accessibility and thus significantly enriching the business model in both terms of user growth, market penetration in terms of geography, demographics, and traffic load, and also in potential pricing of services [31].

Wi-Fi can play a key role in the MNO business model in terms of capacity improvement and coverage extension. Wi-Fi Offload can assist MNO where needed, as complementary solution in outdoor scenarios or as an extension in indoor environments [51], [52].

An example of such model is the “Carrier Hampton” Business Plan is a Local-Loop Whole Sale Provider deployed in the suburbs of Peterborough, UK [53] and can also provide solution for PPDR services, albeit stationary. In this deployment there are two types of customers:

- Direct Customers - Private customers, who use the Wi-Fi Internet Broadband connection with their Laptop, their smart phone, a Wi-Fi-USB Stick or a Wi-Fi card for their PC or a special Wi-Fi router for dedicated or very remote lines. The Police (surveillance cameras) and schools and universities or other large organizations can also become direct customers with a dedicated line.
- Indirect Customers - Internet Service Provider (ISP), Mobile Service Providers, which either have to use the „Local Loop“ of British Telecom or have to rely on radio network with a low data bandwidth capacity, can use the offered local loop with their customers.

next WRC by November 2015. Besides, unlike narrow-band systems where eventually each organisation could have access to a few resources, the future broadband PPDR spectrum will have to be shared between all PPDR organisations (and may be with other critical infrastructure operators). Moreover, since this potential spectrum is in competition with spectrum for commercial operator, there is a risk that the resulting spectrum might be less than what is requested (2x10 MHz are requested by the PPDR community for data services only). In that case, the resulting capacity on a dedicated network can be limited.

- **Cost of deployment** – deploying a new network on a large geographical scale will incur significant investments that need to be planned in advance. Depending on the frequency band that will be allocated for broadband PPDR services and on the output power of the LTE terminals, the required number of sites may be significantly higher than the actual number of sites currently deployed for TETRA or TETRAPOL to cover a similar geography.
- **Skills** – PPDR organisations may have today network operation teams managing the existing narrow-band circuit-switched based network. With next generation PPDR system based on LTE and IP, a new and different set of skills will be required.
- **Time to service** – Deployment of a PPDR network usually takes time (the deployment of TETRA / TETRAPOL network took several years). Indeed, to have a successful deployment happening, there is a need to have a budget matching the requirement, to have the radio sites (prepared) for deploying the new system, to have the right skills and to train the PPDR officers to use the new technology.

A successful deployment of a dedicated broadband PPDR system will need to address the previous points. Multiple business models may exist to deploy and operate this dedicated system but in any case, the owner of the system will have to invest in a complete new infrastructure. To limit the upfront investment, the PPDR organisation may deploy the broadband system in a limited geography. For instance the deployment may start with a few key areas where the need for broadband would be the higher (main cities, main roads...).

Whatever the business model to be used, deploying a dedicated network will consist of deploying a complete LTE network consisting of (see Figure 14):

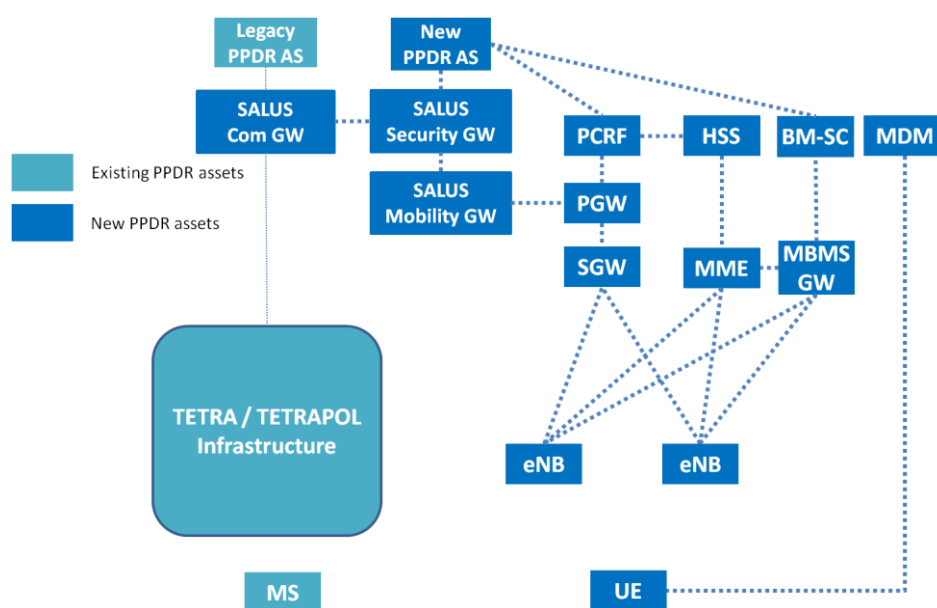


Figure 14 - Dedicated LTE network (simplified)

- LTE Terminals and associated device management platform and applications,
- LTE Radio access network (the eNodeBs).
- LTE core network (unicast and broadcast mode).

Besides, in addition to the above mentioned components, the PPDR organisation might also have to invest in renovating the backhaul network to align it to the requirements of an LTE network (bandwidth, protocols, interfaces, security, synchronisation...).

3.1.2.1 Different business models for getting dedicated broadband services

Build, own and operate – in this model, the PPDR organisation finances, procures, build and manages its own network. It takes full responsibility for all network elements and software, and employs in-house personnel to build, manage, operate and maintain the network. It is to be noted that due to spectrum constraint, only one radio access network will be built and shared by all PPDR organisations. A leading PPDR organisation (or a government body) will then take care of the deploying, maintaining and operating the radio access network. Besides, it is recommended to also have a single core network for all the agencies and to have the same leading entity managing it. With the advance of technology to Network Function Virtualisation (NFV) it will be possible, if desired, to create multi-tenant virtual EPC.

Table 10 gives the CAPEX and OPEX items for the PPDR organisation building, owning and maintaining the broadband PPDR network.

Build Own and Operate	CAPEX	OPEX
Terminals	COTS terminals. Ruggedized terminals MDM platform	Operation and Maintenance of the MDM (HW and SW) with in-house personnel
Network	eNodeB EPC (S-GW, P-GW, PCRF, MME, HSS, BM-SC, MBMS GW) Packet based Backhaul (if owned)	Operation and Maintenance of the network equipment (HW and SW) with in-house personnel Leased lines for backhaul (if leased)
Gateways	SALUS Communication Gateway SALUS Security Gateway SALUS Mobility Gateway	Operation and Maintenance of the Gateways (HW and SW) with in-house personnel
Applications	End-user device (e.g. camera, sensor...) Application software and servers (e.g. video management system...)	Maintenance of application servers (HW and SW) with in-house personnel

Table 10 - CAPEX and OPEX summary for Build, Own and Operate

Own and outsource operations – This model is very similar to the previous one but instead of having in-house personnel managing the network, the network operations are outsource to a specialised company. The service paid to the specialised company may also include upgrades of the system

Public Private Partnership - the LTE network is deployed, operated and maintained by an independent operator. This type of network is typically owned by a commercial MNO, which provides the service to the PPDR organisations while usually assuming the financial, technical and operational risk of the service offer. The MNO may use part of its existing infrastructure to optimise the total cost of ownership of the network (e.g. sharing of radio sites, sharing of

backhaul, etc). It is to be noted that in this model, (and if regulation and legislation allow this mode of operation), it might be possible to “monetize” part of the dedicated PPDR spectrum and open its use to commercial users during off-peak period of the broadband PPDR network. From a technical point of view that would be possible using LTE RAN sharing option.

Table 11 gives the CAPEX and OPEX items for the PPDR organisation and the company providing the PPDR services. It is to be noted that this table indicates the “electronics” part. A global CAPEX and OPEX list should also consider real estate, civil engineering (if needed), power supply, air-conditioning, physical perimeter security, etc which are usually quite high.

Public Private Partnership	PPDR Service provider		PPDR user	
	CAPEX	OPEX	CAPEX	OPEX
Terminals	MDM	Operation and Maintenance of the MDM (HW and SW)	COTS terminals Ruggedized terminals	
Network	LTE eNode B LTE EPC (packet based backhaul)	Operation and Maintenance of the network equipment (HW and SW)		Annual/monthly fees for managed services of network components
Gateways	SALUS Communication Gateway SALUS Security Gateway SALUS Mobility Gateway	Operation and Maintenance of the Gateways (HW and SW)	Additional security solution (option)	Maintenance of additional security solution Annual/Monthly fees for managed services of network components
Applications			End-user devices Application software and servers	Maintenance of application servers (HW + SW)

Table 11 - CAPEX and OPEX summary for the Public Private Partnership model

3.1.2.2 Role of Wi-Fi complementing dedicated PPDR LTE networks

For European scenarios we need to focus on the availability and reliability of dedicated Wi-Fi networks for PPDR services. The main disadvantage of 802.11b/g/n networks [32]-[37] is the lack of a centrally-planned infrastructure that can provide robust coverage of an urban area, considering that metropolitan area networks at the 2.4 GHz are in many cases the product of “bottom-up” networking by communities of users. So coverage may or may not be present at a given location.

Co-channel interference can provide another disadvantage for Wi-Fi access for PPDR services, as Wi-Fi hotspots are deployed without central planning and can co-exist in a way that each hotspot becomes hostile to the others in terms of electro-magnetic radiation.

On the other hand, Wi-Fi access can provide a more reliable solution, either in obstacle-dense micro cells where a base station may not be able to service a mobile user in the presence of shadowing due to physical obstacles or in an indoor environment where outdoor-to-indoor penetration of 3G/4G access might be weaker. Moreover, in macro-BS deployment, the user

moving at cell boundary may suffer from deep fades and marginal signal reception whereas an approximate Wi-Fi hotspot, albeit randomly deployed (either in residential or enterprise topology) can provide a reliable access solution for PPDR services.

Respective business models for Wi-Fi networks and especially Public WLANs (PWLAN) that can assist in PPDR services provided by dedicated LTE networks have been evaluated according to the IDEA (Identify, Design, Evaluate, Aggregate) framework, as shown in Figure 15 [41]-[42].

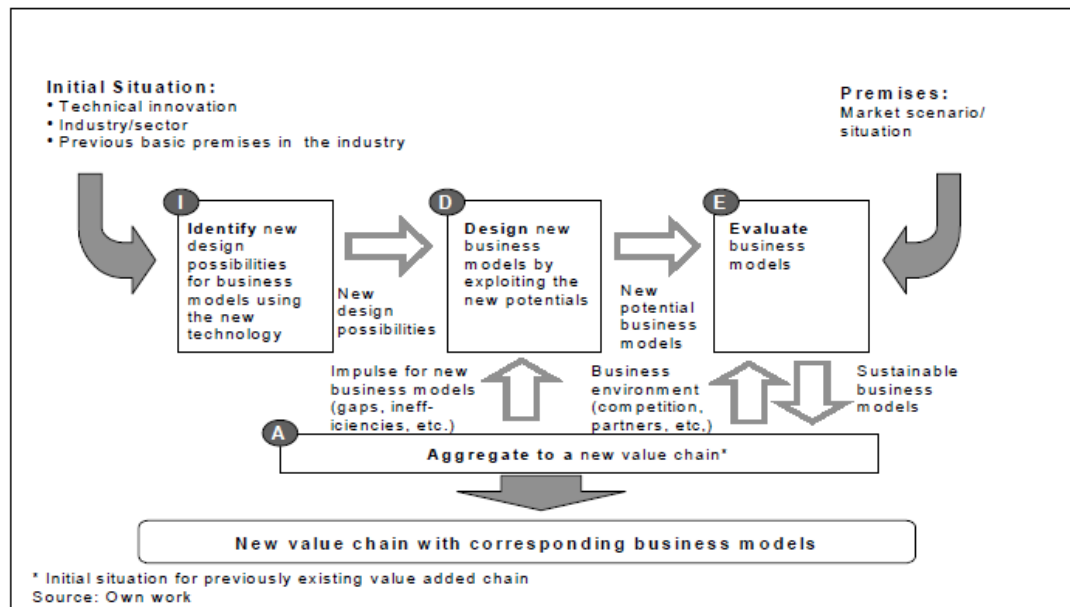


Figure 15 -IDEA framework

The task of “Module I” is to Identify the need for business innovation, when the assumed considerations have changed. These considerations refer to the technological capacities and their presumed impact on business reshaping. The next step is to identify the new possibilities of the redesigning of the business models – what is called the new design possibilities.

The result of “Module D” is to Design a set of new business models using the new design possibilities identified in “Module I”.

In “Module E”, the potential business models, which were identified in the “Module D”, are Evaluated, with the criterion of market success. All business models that are considered for evaluation are ranked according to their performance in assumed market scenarios.

In “Module A”, the business models are Aggregated in a value chain. All identified business models are placed in the value chain with regard to the value – adding activities they deliver in this industry.

Afterwards, the interactions between the business models are analyzed. There are three kinds of interaction: (1) Service Relationship, (2) Competition, (3) Alliances / Coalitions [43].

Figure 16 demonstrates all possible identified and sustainable business models for the Public WLAN market, after excluding irrational combinations of possible scenarios.

#	Business Model	Owner Ship	Value Chain	Description of business model
1	Fully Integrated Operator	Specialized Company	Full Value Chain	Offers PWLAN Internet Access in multi locations. Owning most Access Points as well as having Roaming agreements with some access point owners.
2	WLAN Service Provider	Specialized Company	Relationship Mgt & Sale	Offers PWLAN Internet Access in multi locations. Relying only on roaming agreements with access provider
3	Relationship Management ASP	Specialized Company	Relationship Mgt	Provides Access Provider + with customer authentication and billing functionality -no customer ownership. Coordinates Roaming agreements for access provider.
4	Access Provider	Specialized Company	Access	Owens Access Points in multi locations. Has roaming agreements with Service Provider, but does not have a sales force.
5	WLAN-Content Provider	Specialized Company	Content	Offering Location based Services and Content for PWLAN in multi locations. .
6	Network Planning	Specialized Company	Planning & Deployment	Specialized in planning and deployment of WLAN access points for access provider
7	Reseller	Specialized Company	Sale	Sells contract and prepaid cards for Fully Integrated Operator and WLAN Service Provider in physical stores or online.
8	ISP	Specialized Company	Internet connection	Connects the hotspots to the internet. Get fixed or traffic based fee from PWLAN provider.
9	Small Local Operator	Professional Location Owner	Full Value Chain	Offers existing customer base an additional service only in this location.
10	Venue Access Provider +	Professional Location Owner	Access & Sale	Own the Access Points in their location. Sells contracts and prepaid cards for their own brand (customer ownership) and for PWLAN Provider with which they have a roaming agreement.
11	Venue Access Provider	Professional Location Owner	Access	Owens only the Access Points in their location. Has roaming agreements with Service Provider, but does not have a sales force.
12	PoS Reseller	Professional Location Owner	Sale	Location Owner sells contract and prepaid cards for Fully Integrated Operator and WLAN Service Provider in the hotspot (point of service).
13	Private Access Provider	Private Person	Access	Owens an private Access Point and offers internet access for free or has a roaming agreement with a service provider.
14	Site Rental	Location Owner	Site Rental	Rents his site to a Fully Integrated Operator or to an Access Provider.

Source: Own Work

Figure 16 - Identified and Sustainable Public WLAN Business Models

These business models as well as alliances in the global PWLAN market reflect not only the actual traffic of PWLAN providers and users, but also the challenges in the technological issues still open for wireless networks and services, including PPDR Services for both stationary and (low-speed) vehicular scenarios [44]- [49].

In the final version of the deliverable this analysis will be extended to PPDR case.

3.1.3 Systems on wheels

Mobility of PPDR users in many cases is “vehicle powered” mobility. In many scenarios, the PPDR user is inside a vehicle or in the vicinity of his vehicle when executing his duties. The PPDR vehicles might then be the physical backbone of the PPDR operations. As a result, considering the use of PPDR vehicles as a natural bearer of PPDR (communications) equipment is very logical. Vehicles can actually carry communications equipment for a number of purposes.

First there is PPDR related information and control tightly connected to the vehicle as such. This interaction is through vehicle mounted sensors and actuators. The most common used sensor is GPS for the vehicle position (usually called automatic vehicle location, AVL). But other sensors are also of interest. Some examples are:

- Door opening / closing - when a door is opened while the vehicle is close to the location of an incident, one may conclude that the vehicle is “on the scene”, triggering a status notification to a dispatch room,
- Sensors measuring supplies - e.g. communicating the measured water o supply can trigger the organisation to arrange for refill
- Video and sound sensors – vehicles are more and more equipped with video camera that can record images and sound that can be used to transmit raw and/or processed information to the command and control centres and to play-back records of interest.

The vehicle is also the typical place to have computer based access to databases or video applications. The vehicle is more than a “mobile office”. This application includes a vehicle mounted computer, with keyboard, display and maybe some other peripherals.

Both vehicle specific systems, as well as a vehicle mounted computer require an infrastructure link, which commonly is LTE-based in the SALUS context.

The vehicle however is also the correct carrier for repeater-like systems. The vehicle may contain a “Mobile Node” (MN). Such MN is a router that extends the infrastructure towards mobile clients. This exploits the strength of the vehicle, which can be equipped with better antennas, and with more radios for various networks (to perform always best connection or to aggregate bandwidth from multiple networks).

An even more extreme scenario is when the infrastructure completely lacks in a specific environment. One scenario is a typical disaster scenario where (significant parts of) the infrastructure is lacking at the operational scene (such as use case 3 – disaster recovery - as described in SALUS deliverable D2.3 [50]). The typical reasons would be calamities like power outage or physical damages to parts of the infrastructure due to landslides, hurricanes, intense cold or heat, etc. The other typical scenario is a remote location, outside of the coverage of the infrastructure, like in mountainous terrains. In such scenarios, the vehicle based system, or typically more a system on wheels is a stand-in infrastructure to temporally replace the infrastructure.

The MN may maintain three different types of connections:

- Client on an infrastructure,
- Infrastructure for mobile clients,
- Part of an ad-hoc network to create an ad-hoc backbone.

Each of these types of connections needs to be exploited to its maximum for high quality communications.

3.1.3.1 Client on an infrastructure

A MN may be equipped with multiple radios for the infrastructure connection. When the multiple radios are all LTE-based, each radio may be linked to a different operator (this may include commercial and/or PPDR operator). By doing so, the MN can maximize the quality for its users by combining the quality of the individual networks. Combining this quality can have different shapes. Well known principles are load-balancing, QoS-aware routing and link aggregation. In case of load-balancing and QoS-aware routing the MN will decide per traffic stream which radio to use. The principle of load balancing aims for balancing the load over the available links, creating as much as possible a constant quality. The principle of QoS-aware routing considers the QoS requirements per traffic stream in its decision, which will lead to a more differentiated performance. In case of link aggregation, the available links are combined into a single “bit pipe”. This caters for a very high capacity link, but prevents the LTE system to be QoS-aware with respect to the individual traffic streams.

Being vehicle mounted also caters for use of high gain antennas, and is placed at a higher location. A vehicle mounted omni-directional antenna may have a gain of 6-8 dBi, whereas a handheld device typically has close to 0 dBi antennas. The use of directional antenna on vehicles could be applicable in some scenarios, leading to antenna gains of 14-16 dBi in realistic use cases. That would enable larger reach and/or better data rates around the vehicle location compared to handled connection to the wide area network. Besides LTE, a MN may also connect to the infrastructure using a different technology. Satellite communication is a frequently used back-up (but with limited bandwidth and extra delays), whereas land-line (based on microwave links or wired connection) may be an option in semi-static cases as well.

3.1.3.2 Infrastructure for mobile clients

A MN will be equipped with technology to provide access to mobile clients. The MN may cater this using a range of technologies. Within the scope of the SALUS architecture one may see at least the following options:

- WLAN Access Point,
- LTE – (small) cell,
- Sensor network technology.

A WLAN AP can provide access to a large variety of end-user devices. All state-of-the-art smartphones have WLAN capabilities, so can access a network through the MN. Also other devices, like CCTV cameras, and much consumer grade equipment is WLAN capable. This makes that more or less any device can be linked to the system, being specially designed for PPDR use or not. Providing WLAN Access Point capabilities enables Bring Your Own Device (BYOD) strategies. It also enables easy adaption of business or consumer solutions in the PPDR scope, avoiding specific design effort that is not cost efficient for PPDR specific design only, while being efficient for the large public of consumers or business users.

A second technology that may be integrated in the same MN is LTE. The MN can act as an LTE (small) cell. This could be defined as a cell of one of the existing LTE infrastructure, or could have a separate network code. Using the same network code leads to mobility control being handled by the infrastructure. Using a separate network code would better fit ad-hoc network aspect of the overall solution.

The sensor network option is a third group of technologies. Wireless sensors are part of the upcoming so called IoT. Wireless sensors will enable detailed vision on the field of operation, so will feed the common operational picture. The technology for wireless sensors is not yet very standardized, containing a large group of alternative solutions. A common denominator is the term Low Power Wide Area (LPWA). A selection from these technologies needs to be made for a specific implementation.

3.1.3.3 Ad-hoc network as backbone

When multiple vehicles are within one's vicinity, the vehicles can create a local ad-hoc network. The main purpose of this ad-hoc network is to create a robust in-field backbone for communication. End-user devices are connected as described above, the ad-hoc network extends the infrastructure. The technology of the ad-hoc network can be chosen completely independent from the technologies discussed above, so the technologies for accessing the infrastructure and for creating access to end-user devices. The most logical technologies for access and possibly the ad-hoc backbone are WLAN and LTE.

WLAN has the big advantage of being license exempt, implying that no licensing issues arise when deploying the system in ad-hoc situations. WLAN is a possible technology for this ad-hoc network. WLAN can run in ad-hoc mode, which implies that there is no coordination point within this ad-hoc network. Each MN is responsible for creating its own communication environment. This environment includes at least the physical, networking and security aspects. As the MNs need to be able to communicate also when communication to the infrastructure is impossible, such aspects need pre-configuration. The main merits of WLAN ad-hoc networking as backbone for on-scene communications are:

- Pros:
 - Additional robustness,
 - No need for licensed spectrum,
 - Very cheap, so easily deployed,
 - Multiple hops possible.
- Cons:
 - Ad-hoc networks still require a backbone to connect to the main (strategic and/or tactical level) command and control centre and local application in clients if there is no connection to the main network/applications; it is not a solution in itself,
 - Use of licence exempt spectrum may be impossible due to high load and/or high interference in the area of deployment,

- Range of ad-hoc networks is usually limited due to power limitations in unlicensed bands.

LTE is certainly the other available technology for ad-hoc deployment. In particular the ProSe extension (Proximity Services), which is currently under development, could be used. ProSe provides the option of direct Device to Device communication between LTE devices, but also the option of creating a local network, using only the local eNodeB. ProSe will support unicast, groupcast, broadcast and relying, creating a complete suite of functions to fulfilling any communications requirement. The merits of this approach are the following:

- Pros:
 - Same terminal technology as for day-to-day operation,
 - High bandwidths possible at good ranges,
 - No need for additional spectrum (to be confirmed depending on ProSe implementation options –in band or out of band-),
- Cons:
 - Technology still under development,
 - It remains to be a local network, with limited range,
 - Needs coordination with network for spectrum sharing in case of in-band mode,
 - One hop only for D2D or 2 hops maximum in case of Network to device relays.

3.1.3.4 System on wheels options

Based on the above information, two generic MN can be defined: a MN for coverage and/or capacity extensions (MN – CCE) and a MN for disaster recovery (MN - DR). Also, although the previous sub-sections are dealing with broadband communications, the MN may include a narrowband component.

Figure 17 depicts the simplified architecture of the MN - CCE. In this case, the MN consists of mobile gateways connecting to the wide area cellular network on one side and retransmitting the signals on the terminal side. All applications / SALUS gateways are in the back-office. Main CAPEX and OPEX items for this option are listed in Table 12.

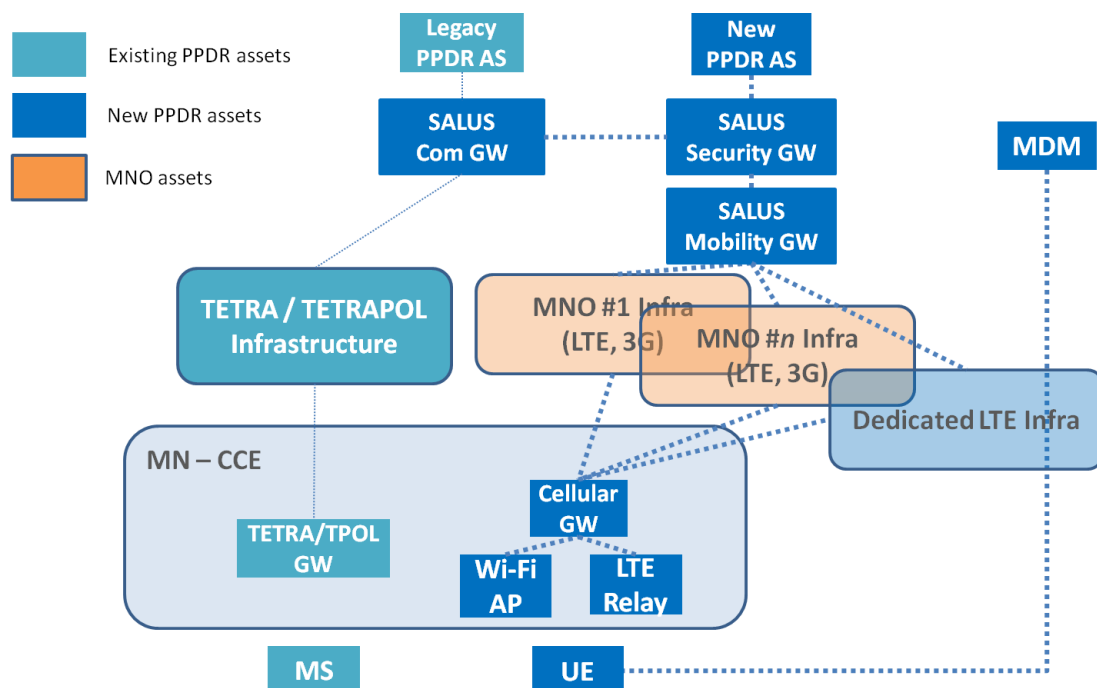


Figure 17 - Simplified high level architecture of MN – CCE

MN-CCE	CAPEX	OPEX
Terminals	COTS terminals. Ruggedized terminals MDM platform	Operation and Maintenance of the MDM (HW and SW) with in-house personnel
Mobile Node	Cellular GW (to connect to the cellular backbone) LTE Relay (ProSe UE or LTE –small- cell) Wi-Fi AP	Operation and Maintenance of the network equipment (HW and SW) with in-house personnel
Cellular Backbone	Dedicated LTE infrastructure (option)	Cellular subscription
Gateways (back-office)	SALUS Communication Gateway SALUS Security Gateway SALUS Mobility Gateway	Operation and Maintenance of the Gateways (HW and SW) with in-house personnel
Applications (back-office)	End-user device (e.g. camera, sensor...) Application software and servers (e.g. video management system...)	Maintenance of application servers (HW and SW) with in-house personnel

Table 12 - CAPEX and OPEX summary for MN - CCE

Figure 18 depicts the simplified architecture of the MN - DR. In this case, the MN consists of complete systems in a box (LTE; Wi-Fi, TETRA and/or TETRAPOL) and also implements all applications / SALUS gateways. Main CAPEX and OPEX items for this option are listed in Table 13.

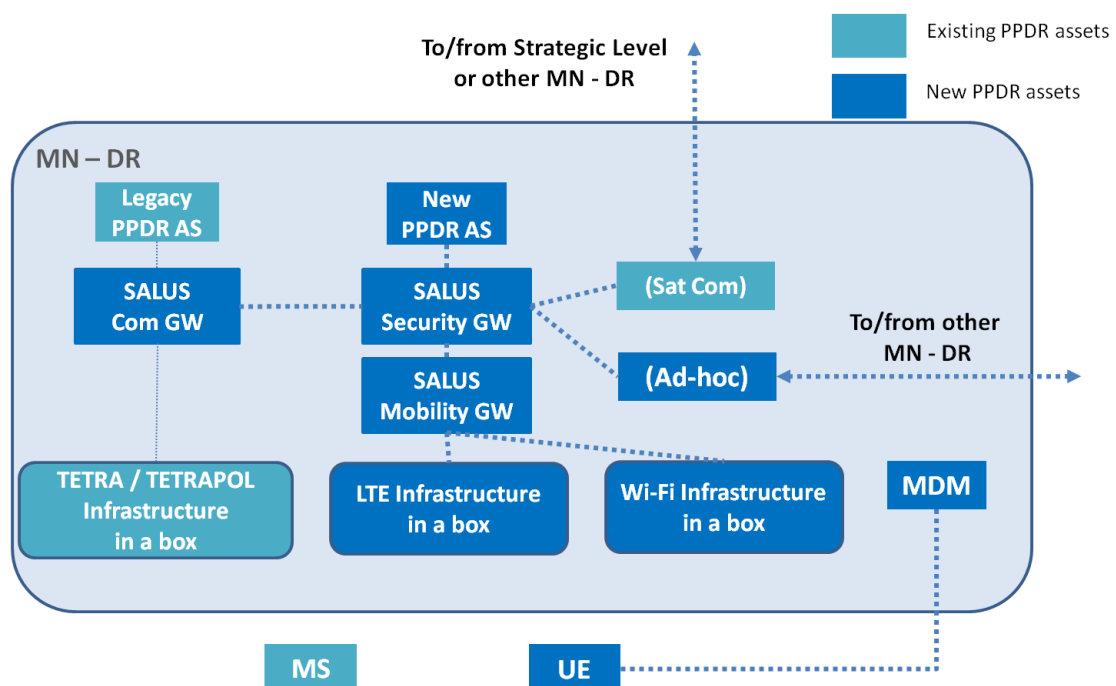


Figure 18 - Simplified high level architecture of MN - DR

MN-DR	CAPEX	OPEX
Terminals	COTS terminals. Ruggedized terminals MDM platform	Operation and Maintenance of the MDM (HW and SW) with in-house personnel (preparation phase) and by local personal to the incident (response phase)
Mobile Node	LTE in a box (RAN, EPC, NMS) Wi-Fi AP SALUS Communication Gateway SALUS Security Gateway SALUS Mobility Gateway End-user device (e.g. camera, sensor...) Application software and servers (e.g. video management system...)	Operation and Maintenance of the network equipment, Gateways and applications (HW and SW) with in-house personnel (preparation phase) and by local personal to the incident (response phase)
Backbone	Satellite modem Wi-Fi Ad-hoc or other for	Satellite service subscription

Table 13 - CAPEX and OPEX summary for MN – DR

3.1.4 Hybrid models

Previous sections have presented individual deployment models and have showed that there is not a single perfect model based on an individual approach. However, in next generation PPDR networks, since the access technologies that will be used are based on commercial standard (LTE, Wi-Fi), this opens also the possibility to combine the previous individual models to get the best of them. In a resulting hybrid model:

- The dedicated wireless broadband system provides a high priority, guaranteed bandwidth for the mission-critical applications always available for PPDR organisations for emergency and disaster response.
- The commercial MNO(s) broadband network can be used as network providing extra-capacity and off-load capabilities for lower priority applications and traffic to further improve the mission-critical aspect of the dedicated network.
- The system on wheels can be used to provide extended coverage and/capacity (via connections to the dedicated and commercial networks) or full autonomous systems in case of major breakdown of the infrastructure.

3.2 Merits of the possible models

The following tables give an indicative and high-level view of the merits of the different models discussed in the previous sections. It utilises a five point rating scale with the following colour code:

- **Red**: Poor
- **Orange**: Fair
- **Yellow**: Good
- **Light green**: Very good
- **Green**: Excellent

In the final version of the deliverable, the merits that are subjective in the following tables will be refined using objective values (especially for the CAPEX and OPEX part that will be derived for the SALUS techno-economical tool).

Model	CAPEX (Network)	OPEX (Network)	CAPEX (Terminals)	OPEX (Terminals)	Time To Service	Coverage (City)	Capacity City)	Coverage (rural)	Capacity (rural)	High Availability	Control	Public Safety features	Security
Standard MNO data plan													
Light PPDR MVNO													
Full PPDR MVNO													
Full PPDR MVNO with specific SLAs													
Build Operate and Maintain (city)													
Build Operate and Maintain (National)													
Own and outsource operations													
Public Private partnership													
MN – CCE													
MN - DR													
Hybrid model (city)													
Hybrid model (National)													

Table 14 - Merits of the different models (low number of PPDR users with broadband capabilities)

Model	CAPEX (Network)	OPEX (Network)	CAPEX (Terminals)	OPEX (Terminals)	Time To Service	Coverage (City)	Capacity City)	Coverage (rural)	Capacity (rural)	High Availability	Control	Public Safety features	Security
Standard MNO data plan													
Light PPDR MVNO													
Full PPDR MVNO													
Full PPDR MVNO with specific SLA													
Build Operate and Maintain (city)													
Build Operate and Maintain (National)													
Own and outsource operations													
Public Private partnership													
MN – CCE													
MN - DR													
Hybrid model (city)													
Hybrid model (National)													

Table 15 - Merits of the different models (high number of PPDR users with broadband capabilities)

4 POSSIBLE MIGRATION SCENARIOS AND ROADMAP

4.1 Roadmap for “early” adopters

Early adopters are considering LTE as a disruptive technology that can replace TETRA and TETRAPOL in the short term (e.g. within the next 2 to 4 years). As with many other disruptive technologies, the potential indeed exists, but due to the current limitations explained in §2.3.2 LTE is not ready yet for mission critical communications, even when using private LTE networks.

Current limitations of deploying standards-based LTE solutions for PPDR include:

- Scalability - group oriented voice, data and video communication are poorly supported in the current 3GPP standards for LTE, resulting in the need to use IP unicast instead of IP broadcast to address multiple LTE terminals in one cell;
- Security - the 3GPP standards-based authentication and encryption algorithms are not public safety grade. This topic is indeed a key topic handled by SALUS project;
- Robustness - the current LTE solutions are developed for operator networks, and do not include extreme resilience features that are required for high availability as required for PPDR networks;
- Spectrum - no (harmonised) spectrum is available for deploying nationwide broadband PPDR networks.

To overcome these limitations there are basically four strategies available as a first step to migrate from TETRA and TETRAPOL to LTE based critical communication in the short-term:

- Use a proprietary LTE solution that addresses the current and temporary lack of standard-based LTE solutions;
- Use current standards-based LTE as an overlay network to existing TETRA and TETRAPOL networks to deliver non-critical (broadband) data and video communications;
- Use current standards-based LTE as an overlay network to deliver non-critical voice using proprietary Over-The-Top (OTT) services, data and video communications;
- Use current standards-based LTE as an overlay network to deliver non-critical voice, data and video communications using an open ecosystem for delivering Over-The-Top (OTT) services.

The second step is the deployment of 3GPP Release 13 standards-based LTE with Group Communication, Proximity Services and eventually IOPS. Ideally, the first step should be aligned with the second step to deliver a smooth migration scenario, whereby no investments are wasted and no big-bang migration scenario applies.

Another important consideration is the limited availability of spectrum and limited budgets for deploying private LTE networks for PPDR. Because no harmonised spectrum is available now for broadband PPDR communication below 1 GHz, both private and fast deployable LTE networks may need to temporarily operate on higher frequencies, like the licensed TDD LTE bands around 2.6 and 3.5 GHz (that usually have not been allocated to MNO in most European countries). This means that the coverage is severely limited and cost is prohibitive for building a nationwide private LTE network; as an indication nationwide coverage of The Netherlands using a 2.6 GHz LTE network would require approximately 4,000 base stations instead of just 600 using 400 MHz TETRA. However, and depending on the upcoming decision at WRC-15, it may be possible for few member states to deploy LTE on dedicated network at 700 MHz and/or 400 MHz in the short-term.

The SALUS consortium supports the development of standards-based critical communications by active participation of its members within 3GPP and ETSI technical working groups. In addition, pragmatic solutions are developed as a first step to integrate and later migrate from TETRA and TETRAPOL to LTE according the fourth strategy.

The benefits and limitations of each of the migration strategies are listed in Table 16.

Aspect	Proprietary LTE	Standard LTE Data & video	Standard LTE Prop. OTT	Standard LTE SALUS OTT
Solution for public LTE networks	--	++	+	++
Solution for private LTE networks	+	++	++	++
Solution for fast deployable LTE	+	++	++	++
Roaming public / private LTE	--	+	0 / +	++
Feature set	-	-	0 / +	++
Integration with legacy PMR	-	n/a	unknown	++
Scalability for group calls	+	n/a	unknown	-
Support of security services	0 / +	- / 0	unknown	+
Robustness	0 / +	0	0	0
Architecture prepared for Rel. 12	--	n/a	unknown	+
Vendor lock-in	--	++	-	+

Table 16 - Benefits and limitations of LTE migration strategies

Examples of applicable solutions include the following:

- Proprietary LTE: Huawei eLTE or ZTE 4G-GoTa. It is to be noted that this approach is not compatible with the use of commercial networks;
- Standard LTE with support of data and video: standard web browser access as well as generic and custom-specific applications running on LTE-connected notebooks, smartphones and tablets;
- Standard LTE with proprietary OTT apps: Motorola/TwistedPair, Kodiak InstaPoC (non PoC version).

It is obvious that the first "proprietary LTE" strategy is not of interest for PPDR organisations, in particular because of vendor lock-in, no support of roaming to public LTE networks, and the limited feature set. Standard LTE based data and video applications are already wide deployed within PPDR organisations for non-critical applications, but these are limited to a few use cases only. Proprietary OTT solutions are definitely a choice as a first step for migration to LTE, especially to offload regular traffic from the TETRA and TETRAPOL networks, but are severely limited in terms of feature set and support of security services (note: will be analysed further in D6.5). The SALUS OTT solution overcomes this limitation by providing an extensive TETRA inspired feature set that is compatible with existing TETRA networks, also in terms of security services, and an ecosystem that is open for other partners as well.

The roadmap for an early adopter could be the following.

For member states getting dedicated spectrum for broadband PPDR below 1 GHz an example of roadmap is found in Figure 19. LTE deployment could start in main cities or main focus area. As soon as SALUS GWs are available, the PPDR organisation can integrate PTT application

and other applications such as location or body area sensors between broadband and narrowband systems. Then, as soon as mission critical features are available (usually 18 to 24 months after the standard), the PPDR organisation may upgrade the infrastructure software and refresh the broadband LTE terminals to benefit from latest ProSe enhancements. At this stage the PPDR organisation will have mission critical (MC) services on both the narrowband and dedicated broadband network. During all these steps, the PPDR organisation may also use one or several MNO to off-load non-mission critical traffic. Finally when the dedicated network coverage is as good as the TETRA or TETRAPOL network, the narrowband network can be decommissioned.

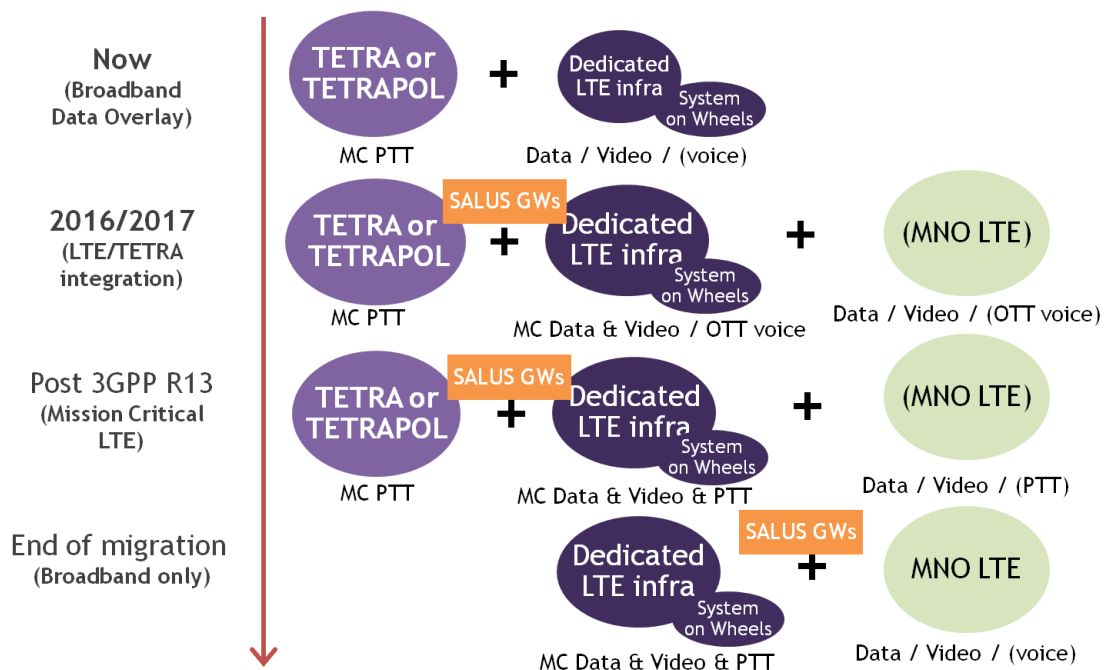


Figure 19 - Example of roadmap for early adopter and dedicated frequency below 1 GHz

An example of roadmap for early adopters with frequency band above 1 GHz is described in Figure 20. In this case, since the dedicated frequency band might be at a rather high frequency, it will not be possible to deploy a dedicated nationwide broadband PPDR network.

However, with the dedicated frequency, PPDR organisation can use as a first step system on wheels to cover main events and invest in deploying a dedicated infrastructure in main cities and/or main focus areas. The consequence is that to benefit from broadband services nationwide, the PPDR organisation will have to establish a full MVNO using one (or more) MNO access networks and establish strict Service Level Agreement (SLA) with them so that they provide 1) Public Safety features on the MNO network, 2) ubiquitous nationwide coverage, 3) highly resilient network and 4) planned (and agreed) maintenance period to avoid outages in major planned event and control outages for all other cases.

An example of roadmap for early adopters with high frequency band is described in Figure 21. In that case, the broadband service is only provided by the access network of an MNO over which the PPDR organisation can deploy MVNO services. Strict SLA with the MNO will ensure that the MNO upgrade and maintain its network so that it can provide the required services, features, resiliency and availability as described in the previous case.

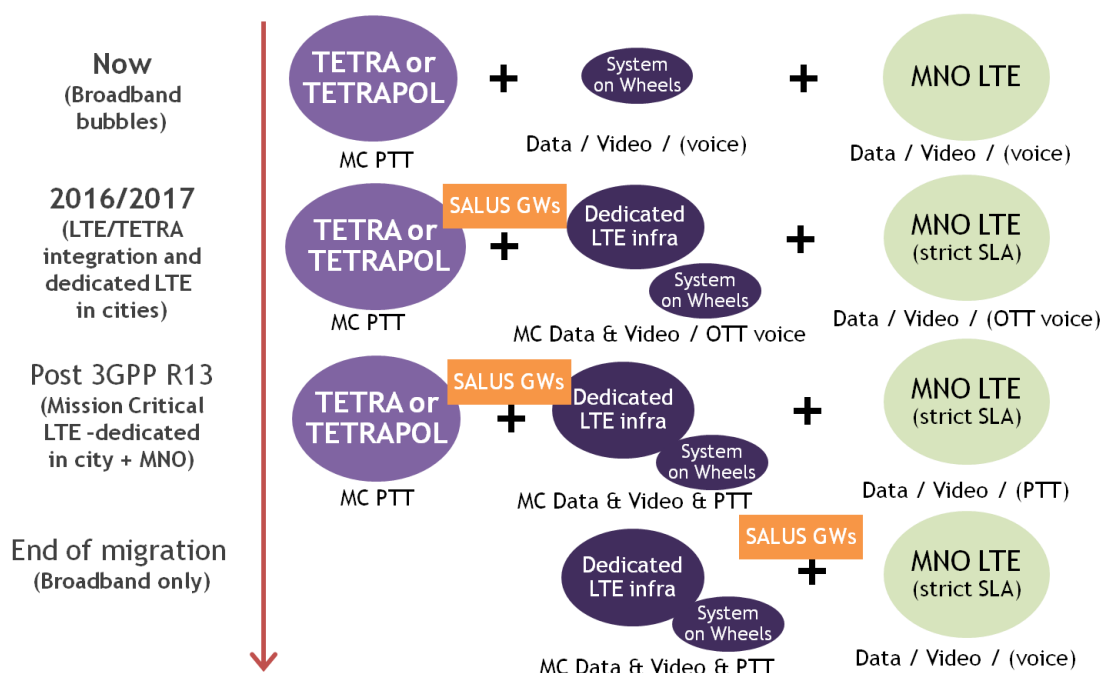


Figure 20 - Example of roadmap for early adopter and dedicated frequency above 1 GHz

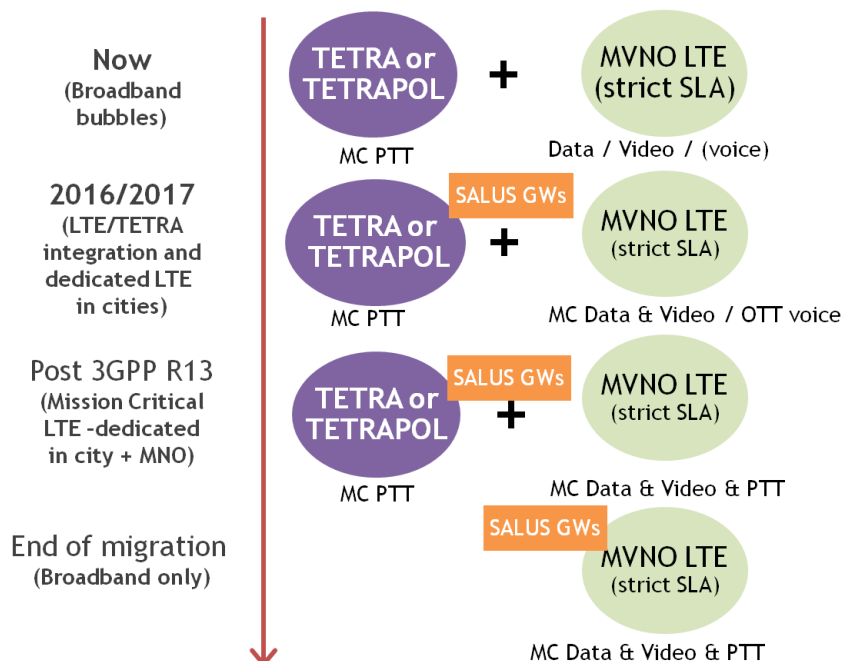


Figure 21 - Example of roadmap for early adopter without dedicated broadband frequency

It is to be noted that in the previous examples but more generally for early adopters:

- Investments on the narrowband network should be minimum (limited mainly to maintenance) and most of the investment should be put on the broadband network (LTE and Wi-Fi);
- The decommissioning of the TETRA network could happen somewhere around 2020;
- The spectrum freed by the decommissioning of the TETRA or TETRAPOL network between 380 and 400 MHz could be used to deploy a layer of LTE at this frequency.

4.2 Roadmap for “late” adopters

Late adopters are considering that LTE cannot replace TETRA and TETRAPOL in the short to mid-term (e.g. within the next 5 to 10 years). However, PPDR users of late adopters would also require broadband services in the short term. In that case, the PPDR organisations will probably favour an approach with:

- Minimum investment on the broadband services; they would get ‘standard’ services from a MNO (through e.g. a MVNO approach) and would only equip a limited number of PPDR vehicles and officers with broadband services;
- Continued investment on the existing TETRA and TETRAPOL systems with eventually a mid-life refresh of this network giving an extra 10 to 15 years of services.

Figure 22 and Figure 23 give example of roadmap for late adopters. The steps are somehow similar to the ones described in the previous section but the intensity of deployment of the broadband services is low at the beginning and the overall timing spans 10 to 20 years instead of 5 years. Consequently, when the late adopters will start deploying broadband services, LTE systems will have all mission critical features available.

Also, as for early adopters, when the TETRA or TETRAPOL network will be decommissioned, it may be possible to benefit from the freed spectrum to deploy a dedicated broadband network layer in this band.

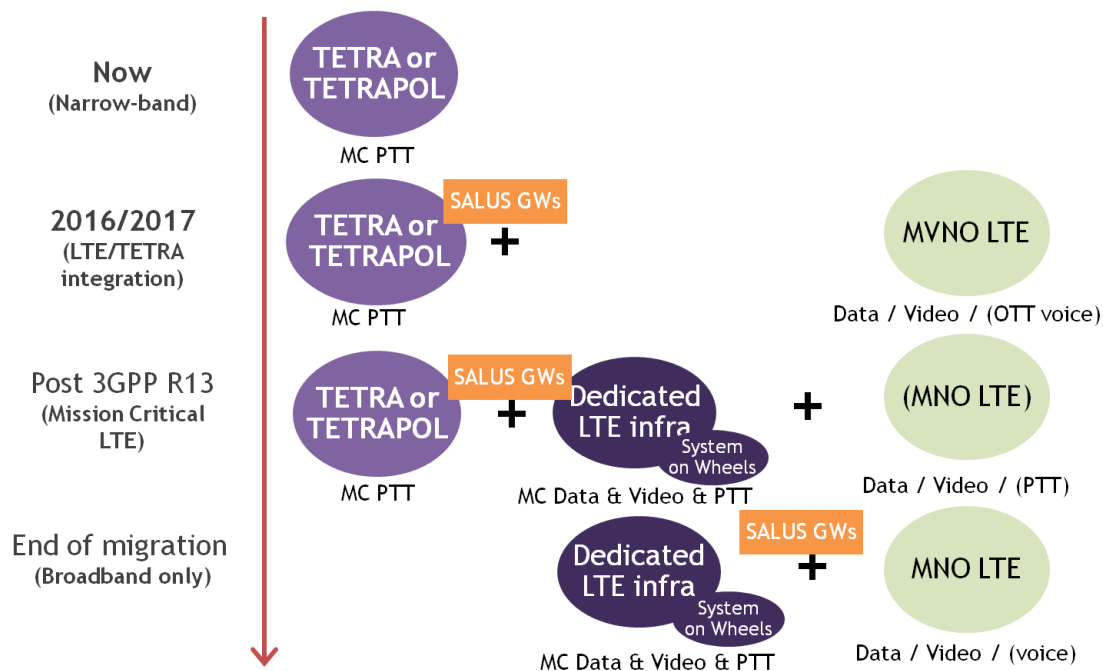


Figure 22 - Example of roadmap for late adopter and dedicated frequency below 1 GHz

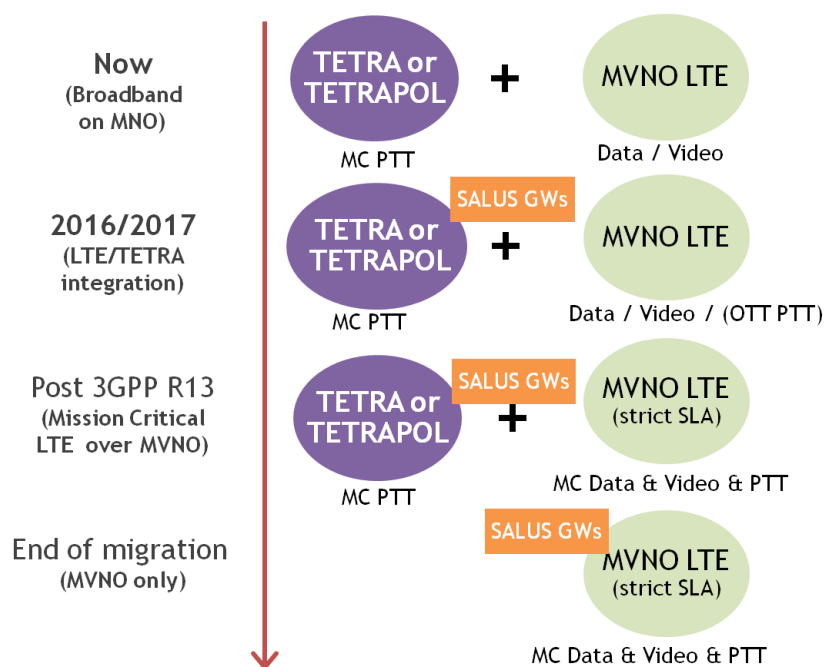


Figure 23 - Example of roadmap for late adopter without dedicated broadband frequency

5 CONCLUSIONS

This deliverable is the intermediate version of the SALUS business analysis and covers multiple aspects such as technology, business models and roadmap.

It first gives an overview of the existing and emerging technologies that will be available for building future PPDR systems. That overview highlights that from a technology point of view, LTE will be ready for supporting mission-critical services starting from 2018+ (e.g. around 2 years after the completion of the 3GPP Release 13 standards). However, deploying a dedicated broadband network requires dedicated spectrum. At the time of writing this report, the decision of allocated dedicated (harmonized) spectrum across Europe has not been taken. Options are being discussed in 400 MHz band and/or in 700 MHz. More information will be available after WRC-15 (November 2015). In the final version of the business analysis deliverable, the technology section will be augmented with:

- Advances in 3GPP standards regarding Public Safety features but also other features that could be of interest for PPDR such as MTC, LTE-U (e.g. LTE in unlicensed bands) or 5G;
- Advances in decisions on dedicated broadband for PPDR.

The second main section describes the different possible business models to deploy a broadband PPDR system. This covers three major models based on either:

- Services from a commercial MNO,
- Services from a dedicated LTE network (city wide, region wide or nationwide),
- Services from cell on wheels (used either as coverage and/or capacity extension or as an autonomous system).

For all models, a high level view of the CAPEX and OPEX items is proposed. A qualitative analysis of the merits of the different models is also given. This leads to the 'obvious' conclusion that the best possible model from a qualitative perspective should be a hybrid model mixing the three main models. In the final version of the business analysis deliverable:

- Aspects of using Wi-Fi for broadband PPDR services will be further explored,
- Quantitative analysis of the different models will be provided using SALUS Techno-Economic tool,
- Additional regulatory obligation per country will be given to further explore the likelihood of using commercial MNO as access network,
- Additional business models may be given.

Finally, first tentative high level roadmaps are given for early and late adopters. This section highlights the fact that it is important for early adopters to invest in standard based LTE technology (augmented by SALUS GWs to enhance interworking with TETRA and TETRAPOL network and the security aspects). In the final version of the business analysis this section will be significantly updated based on the additional inputs provided by the two previous items.

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ACRONYMS

3G	Third Generation Cellular System
3GPP	Third Generation Partnership Program
4G	Fourth Generation Cellular System
AGA	Air-Ground-Air
AP	Access Point
APCO	Association of Public Safety Communications Officials
AS	Application Server
AVL	Automatic Vehicle Location
BATMAN	Better Approach To Mobile Adhoc Networking
BM-SC	Broadcast Multicast Serving Centre
BGW	Border Gateway
BYOD	Bring Your Own Device
CAPEX	Capital Expenses
CCTV	Closed Circuit Television
CEPT	European Conference of Postal and Telecommunications Administrations
COTS	Commercial Off The Shelf
DARPA	Defence Advanced Research Projects Agency
D2D	Device to Device
DEA	Diameter Edge Agent
DMO	Direct Mode of Operations
E2E	End-to-End
E2E VPN	End-to-End Virtual Private Network
EIRP	Equivalent Isotropic Radiated Power
eMBMS	Enhanced Multimedia Broadcast Multicast Service
eNB	eNodeB
ETSI	European Telecommunication Standard Institute
FCC	Federal Communications Commission
GCAS	Group Communication Application Server
GCSE	Group Communication System Enabler
GSM	Global System for Mobile
GoS	Grade of Service
GPS	Global Positioning System
GW	Gateway
HSS	Home Subscriber Station
HW	Hardware
IBSS	Independent Basic Service Set
IETF	Internet Engineering Task Force
IOPS	Isolated E-UTRAN Operations for Public Safety
IoT	Internet of Things
IPX	IP exchange
LTE	Long Term Evolution

LPWA	Low Power Wide Area
MANET	Mobile Ad-hoc Network
MC	Mission Critical
MCPTT	Mission Critical Push-to-talk
MDM	Mobile Device Management
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MNO	Mobile Network Operator
MTC	Machine Type Communications
MVNE	Mobile Virtual Network Enabler
MVNO	Mobile Virtual Network Operator
OLSR	Optimized Link State Routing Protocol
OPEX	Operational Expenses
PAMR	Public Access Mobile Radio
PCRF	Policy Control and Rating Function
PGW	Packet Data Network Gateway
PMR	Private Mobile Radio
PPDR	Public Protection and Disaster Relief
ProSe	Proximity Services
PTT	Push-To-Talk
SGW	Serving Gateway
SLA	Service Level Agreement
SW	Software
TCCA	TETRA + Critical Communications Association
TDMA	Time Division Multiple Access
TETRA	Terrestrial Trunked Radio
TMO	Trunked Mode Operation
UHF	Ultra High Frequency
VHF	Very High Frequency
VoLTE	Voice over LTE
WLAN	Wireless Local Area Network
Wi-Fi	Wireless Fidelity
WRC	World Radio-communications Conference