ICT- 619555 RESCUE

D5.1 Version 1.0

RESCUE impact on industry

Contractual Date of Delivery to the CEC:	04/2014
Actual Date of Delivery to the CEC:	
Editor:	Hicham Khalife
Authors:	Hicham Khalife, Damien Lavaux, Sebastian Gurgul
Participants:	*(TCS, FQS)*
Work package:	WP5 – Dissemination, standardisation and exploitation
Estimated person months:	3
Security:	**PU**
Nature:	**R**
Version:	1.0
Total number of pages:	23

Abstract: This deliverable describes the impact of the RESCUE project on the industrial partners' roadmaps and their products. A particular focus is made on the public safety area an area of a high interest for Thales Communications & security. After describing the PPDR domain, actors, and applications, we study the impact of the RESCUE paradigms on the future of these communication technologies. We also draw in this document a possible roadmap for exploiting RESCUE results in future PMR products of Thales.

Keyword list: PPDR market, PPDR services, PMR evolution, Exploitation plan,

Disclaimer:

Executive Summary

This deliverable describes the expected impact of the RESCUE project on the public safety market and more precisely on the corresponding products roadmap of Thales. One of Thales objectives is to gain shares in the scattered PMR market. In order to achieve this goal, Thales is betting on large deployments of LTE based solutions and particularly in emerging countries. However, in order to differentiate its offers from its competitors Thales is pushing for major innovations and breakthroughs while remaining compatible to the ongoing LTE standardisation for public safety.

The advanced coding solutions to be developed in RESCUE constitute one of these innovations that Thales is exploring seriously in order to enrich its coming offers. Logically, these solutions have very low TRL today and their exploitations can be envisaged only on the longer terms. Still, this long term vision is essential for companies' survival especially in the very fast evolving technological areas.

In this document we provide a comprehensive study on PPDR systems. We describe the main actors, the provided and expected services, and describe the market and its actors. We then give insights on how the solutions provided within the RESCUE project can be exploited by Thales in their future products. Actually, many factors will affect the exploitation of the obtained results in tomorrow's product. First, the success of this project is the main enabler. Second, standardisation initiative as well as market and economical issues can also impact this technology transfer. We take into account all these aspects in investigating the impact RESCUE will have on public safety market in general and more precisely from Thales point of view.

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List of Acronyms and Abbreviations

Term	**Description**
AVL	Automatic Vehicle Location
CCC	Command and Control Centre
ECC	Electronic Communications Committee
FCC	Federal Communications Committee
HSPA	High Speed Packet Access
LAN	Local Area Network
LEWP-RCEG	Law Enforcement Working Party of EU- Radio Communication Expert Group
MAC	Medium Access Control
MAN	Metropolitan Area Network
MANET	Mobile Ad-hoc Network
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
PMR	Professional Mobile Radio
PPDR	Public Protection and Disaster Relief
QoS	Quality of Service
RSPG	Radio Spectrum Policy Group
TCCA	TETRA + Critical Communications Association
TCO	Total Cost of Ownership
TETRA	Terrestrial Trunked Radio
TRL	Technology Readiness Level
UMTS	Universal Mobile Telecommunications System
WAN	Wide Area Network

1. Public Safety Users and Requirements

Public protection and disaster relief (PPDR) is the general designation given to a range of public safety services. The formal definitions of PPDR derive from Report ITU-R M.2033 [5]"Radiocommunication objectives and requirements for public protection and disaster relief". They can be summarized as follows:

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

Before studying the impact of emerging technologies on the evolution of PPDR, we first give a detailed description of the current solutions, as well as their offered services and applications.

1.1 Categories of end users

The foreseeable end users of a PPDR system are the members of all the PPDR organisations. PPDR applications are employed by a large number of users (typically of the order of 1% of a country's population) including both first responders acting in situ and operational field officers at the CCC premises. Informally, the users of PPDR system consist primarily of:

- police, fire and emergency medical services
- Also included within the ambit of PPDR are search and rescue, border security, event security, protection of VIPs and dignitaries, evacuation of citizens, and other aspects of the response to natural and man-made disasters.

In order to cover efficiently the defined end users, European countries have deployed their PPDR solutions largely dominated by the TETRA standard and its variations (TETRAPOL). The figure below shows the used technology in each country.

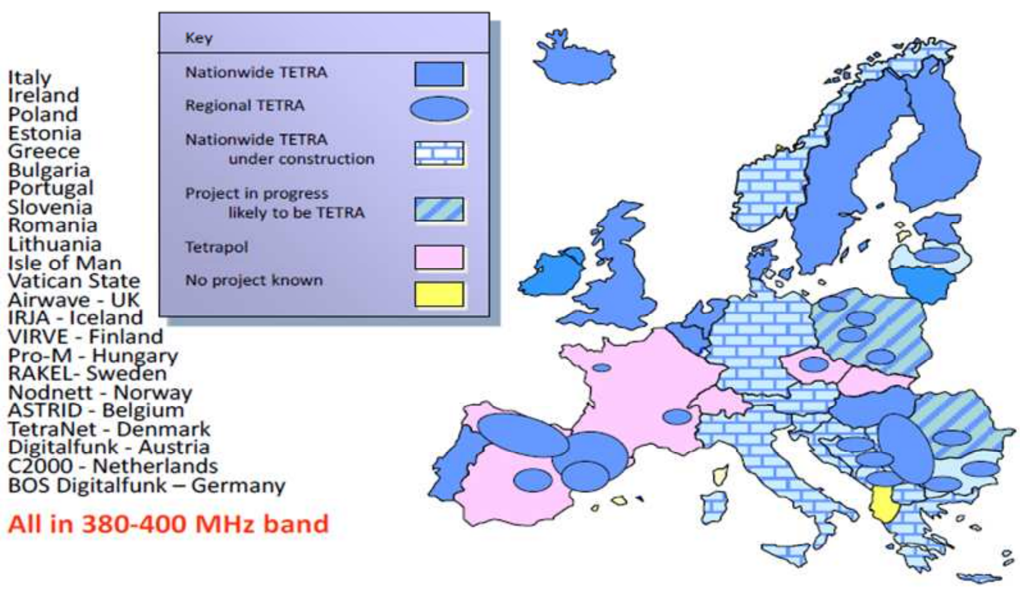

Figure 1 PPDR deployments in EUROPE Source : LEWP-RCEG, TCCA-CCBG User & operator group

As highlighted in ***Figure 1***, these public safety networks in addition to the heterogeneous employed solutions they are managed by different operators. This situation makes interoperability in the case of border operations difficult to achieve. Most importantly, TETRA remains essentially a voice narrowband solutions that shows many limitations when it comes to today's applications and higher data rates.

1.2 Services

The set of services that are potentially interesting for PPDR agencies and their operations are known to Thales. These applications and services were selected mostly based on the information coming from Electronic Communications Committee (ECC) draft reports and on particular needs identified by the end-users during the requirement gathering phases. These services are described in the following subsections and include:

- **Voice (common PPDR voice services)**
  - Push-to-talk
  - Private call
  - Group call
  - Emergency/priority call
  - Call retention/busy queuing
  - Direct mode operation
  - Ambience listening
  - Voice over the public switched telephone network (PTSN)
  - Area selection/dynamic group number assignment (DGNA)

- **Narrowband data (data transmission up to 384 kbps**)
  - Messaging and notifications
  - Low resolution photos
  - Automatic telemetrics
  - Location-based information
  - Mobile workspace applications
  - Access to internal databases
  - Access to external sources

- **Broadband data (data transmission above 384 kbps)**
  - Rapid file transfer
  - High resolution photos
  - Remote operations
  - Mapping with geographic information system (GIS) layers
  - Mobile workspace applications
  - Access to internal databases
  - Access to external sources

- **Video (data transmission with tighter latency and coding requirements)**
  - Video transmission
  - Video streaming
  - Video call

- **Transversal services (extension of voice and data capabilities and performance)**
  - Extension of coverage
  - Extension of availability
  - Encryption tools

- **Challenging services (services enabled by the next generation of technologies)**
  - Proximity services
  - Augmented reality

The drivers for increased bandwidth, and thus for increased data rates, for public safety mobile broadband are numerous and complex. In particular, new demands such as broadband data exchange, video, and challenging services constitute most relevant ones. These observations motivate the need for a new generation of PPDR communication systems that are capable to offer high data rates and broadband communications in addition to the high resilience and availability features.

2. Technical Needs and Limits

This section summarises and briefly describes the technical needs and limits that are most relevant to public safety area. Following the same logic of that document, this section is further organised according to the technical gaps that are common to distinct network categories: current PPDR technologies, public networks and candidate technologies for future PPDR applications.

2.1 Current PPDR technologies

The most relevant technological gap that is common to current PPDR networks corresponds to the inability of these technologies to comply with PPDR requirements for high speed data transmission, today's technologies generally having data rates below 384 kbit/s. For this reason, specific data communications requirements (such as the transmission of broadband data) cannot be fully met when these technologies are employed.

Furthermore, analogue PMR systems have severe limitations in terms of security and voice communications, being therefore at the end-of-life. Note however that, in some applications, analogue systems may be preferred due to the "gradual degradation" in poor signal conditions rather than the "cliff edge" effect with digital technologies.

In addition, satellite communications (SATCOM) present also a series of other limitations to comply with the user needs, including the likelihood of congestion for a high number of users in the same area, the incapability of direct mode communications, slow call set-up times and the inexistence of some mission-critical voice services and high-security encryption algorithms.

2.2 Public networks (2G/3G cellular networks)

Public networks are characterised by a set of common technological limitations when it comes to the needs of PPDR users:

- Most of these technologies are narrowband only and, even if broadband is supported (e.g., UMTS and HSPA), very high data rates cannot be achieved under all conditions (e.g., high mobility or towards cell edge);
- Lack of a "direct mode" (terminal to terminal) capability;
- Voice call set up is slow (typically up to 5 seconds);
- Additional end-to-end encryption may be required by some users (e.g., police forces);
- No satisfactory push-to-talk (PTT) or group calling implementations exist as a standard.

For these particular reasons, currently deployed mobile networks cannot be exploited for PPDR in their actual state. Technical evolutions are required to integrate the previously pointed issues. Such enhancements should also be accompanied by relevant standardization activities.

2.3 Candidate technologies (LTE, Wi-Fi, WiMAX and MANETs)

Candidate technologies for future PPDR applications are also characterised by the following technological gaps:

- Because of the high frequency band in which Wi-Fi, WiMAX and MANETs typically operate, these networks have a local-area approach, being unable to provide wide coverage areas (although multi-hop transmissions are possible with MANETs). Furthermore, because of their IP-based nature (for enhanced interoperability), only VoIP calls are supported, known for their slow set-up time and performance degradation with higher network loads. This also means that mission-critical voice services will not be natively available when using these technologies;
- In addition, in terms of availability, Wi-Fi and WiMAX connections may become unreliable due to the use of shared licence-exempted spectrum, especially at higher frequency bands. This is especially true for Wi-Fi in urban and high-density areas where many public networks are deployed for personal and business use. WiMAX, on the other hand, provides advanced mechanisms to ensure QoS per user and per service basis to prioritise services for specific users;
- LTE still presents some limitations in terms of network topology and node connectivity models as proximity services and group call system enablers will only be introduced in LTE R12. In addition, jamming LTE base stations is concretely feasible and at the reach of the average person. The LTE signal is complex, made up of many subsystems and, by taking out one of them, the entire base station goes with it ("Isolated eUTRAN" operations are only expected for future releases);
- Wi-Fi has a high dependability on the mobility scheme (high/low speed rates), distance from the access point (network point of attachment) and number of users competing for access. In addition, it should be enhanced with appropriate security policies and authentication mechanisms (possibly external to the network) to satisfy the required security level (e.g., to prevent call interception);

- MANETs allow the addition of more devices in the network to extend overall coverage or to increase available bandwidth/reliability but, with the addition of more nodes, some MANETs will become more congested, leading to lower performances in terms of throughput and latency.

2.4 Existing justifications and recommendations on the usage of LTE

The RSPG report on strategic sectorial spectrum needs (November 2013) recognises that a decision on deployment of broadband PPDR networks is a national matter, but expects to see LTE technology to be the future technology to meet broadband PPDR needs.
Similarly, the LEWP-RCEG has concluded in their meetings that PPDR wants to be part of the global LTE ecosystem because of several advantages including more choice of terminals, lower prices, roaming with commercial networks and long term further developments. LTE is already the technology of choice for broadband PPDR in some countries, e.g. the US where the FCC mandated the use of LTE to provide broadband PPDR services in the LTE band 14, 2 x 10MHz within the 700MHz band. Other countries that have made spectrum available for broadband PPDR purposes in LTE compatible bands include Canada (from the 700MHz band) and Australia (from the 800MHz band).

3. Global Picture of Public Safety Market

The notion of a business model has been in widespread use since late nineties. A multitude of approaches and definitions have been proposed and reviewed [ITU1] [ZAM11] [BW11], mostly from a point of view of an abstract company and its revenue. The focus of this project is on analysing technologies and architectures rather than an enterprise, the main addressee of recommendations being the PPDR community with stakeholders of various roles. The elements used to construct business models reflect the broad range of options analysed in the project, including a range of actors as well as value and cash flows, though the dominant view is supposed to be that of a PPDR service organisation.
As a reference to compare the scope of the business models analysed, a definition of Timers could be called upon, which describes a business model as an “architecture for the product, service and information flows, including a description of the various business actors and their roles”, “a description of the potential benefits for the various business actors”, and “a description of the sources of revenues” [PT98].
The key types of elements for the proposed business models are products or services, actors or entities, resources and capabilities, as well as future trends.

3.1 Services

Products and services in the marketplace are sustained only when they successfully address a market need and create values. In business models for communications systems services can be considered at different levels:

- bearer services:
  - digital channels,
  - signal broadcasting;
- basic end-user services:
  - voice,
  - data,
  - message;
- value-added services:
  - individual call,
  - group call,
- applications:
  - softphone for voice/video calls,
  - AVL (location service),
  - Databases
  - Video streaming/transmissions

Service offers can be merged to create a bundle. A provider can also offer a comprehensive product with a wide package of different solutions, ranging from a set of services to whole systems with many applications.
The classification of services of interest for PPDR was already covered in this document and encompasses the following areas:

- Voice (common PPDR voice services):

- Narrowband data (data transmission up to 384 kbps):
- Broadband data (data transmission above 384 kbps):
- Video (data transmission with tighter latency and coding requirements)
- Transversal services (extension of voice and data capabilities and performance)
- Challenging services (services enabled by the next generation of technologies)

Many services from the list above can be provided by some transmission systems, so it is possible to merge possibilities of several networks to meet user needs.
A variation in business objectives is likely to result in inconsistent security levels in networks and services offered and a threat to the consistent seamless-roaming service. Examples include:

- **market protection strategy** — as mobile data traffic volumes increase to unprecedented levels, some operators will adopt 4G to alleviate problems of network congestion and bandwidth bottlenecks on their current infrastructure. These operators are likely to implement 4G in high-density hot zones, with network upgrades to 4G in phases over the longer term. Such operators tend to offer 4G as an extension of their existing 3G networks and introduce security risk as they work through interoperability issues between various access technologies within their own infrastructure and operations. Operators in this type of deployment strategy encounter operational, performance and security management issues that are threats to the quality of subscriber experience. Poor service quality can result in operators losing their customer base, risking their primary business objective of market protection.
- **market leadership strategy** — operators with market leadership objectives opt for full 4G network rollouts. These operators capitalize on the service quality of 4G as a competitive differentiator. These MNOs would position 4G LTE as a premium service, implement security architectures as recommended by the 3GPP and promote the full suite of feature-rich capabilities of 4G LTE. While this deployment has a robust security infrastructure, the operators assume financial risk of upfront capital and operational expenses to achieve business objectives. If there is inadequate market take rate, these operators may not achieve targeted returns on investments.
- **first-to-market strategy** — operators with the primary objective of speed to market are known to turn up the basic infrastructure and cut corners by deferring deployment of expensive security infrastructure. This approach presents serious security vulnerabilities for the operator's operations, partnering operators and the subscriber, and can cost the operator its reputation and its business.

3.2 Entities involved

For the analysis of different business models that allow arranging systems to offer services to users, different entities and relations between them should be taken into account. These entities belong to the following categories:

- user:
  - PPDR,
  - governmental, municipal,
- operator:
  - of fixed, wireless, mobile networks,
- capital group – to which an operator belongs:
  - e.g. Orange, T Mobile, etc.,
- infrastructure owner – delivers the network infrastructure to the operator to enable the service provision to users,
- service provider – provides services with support from the operator:
  - access or transport network,
  - collocation,
  - content,
  - application,
  - service/support,
- procurer –buying for himself or being a payer (sponsor) for another entity that is associated with it,
- equipment supplier:
  - core, backbone, distribution, edge access infrastructure,
  - WAN, MAN, LAN,
  - terminals,

- Partner - supports an entity in the delivery chain.

In ***Figure 2*** examples of value and financial relations between entities are given.

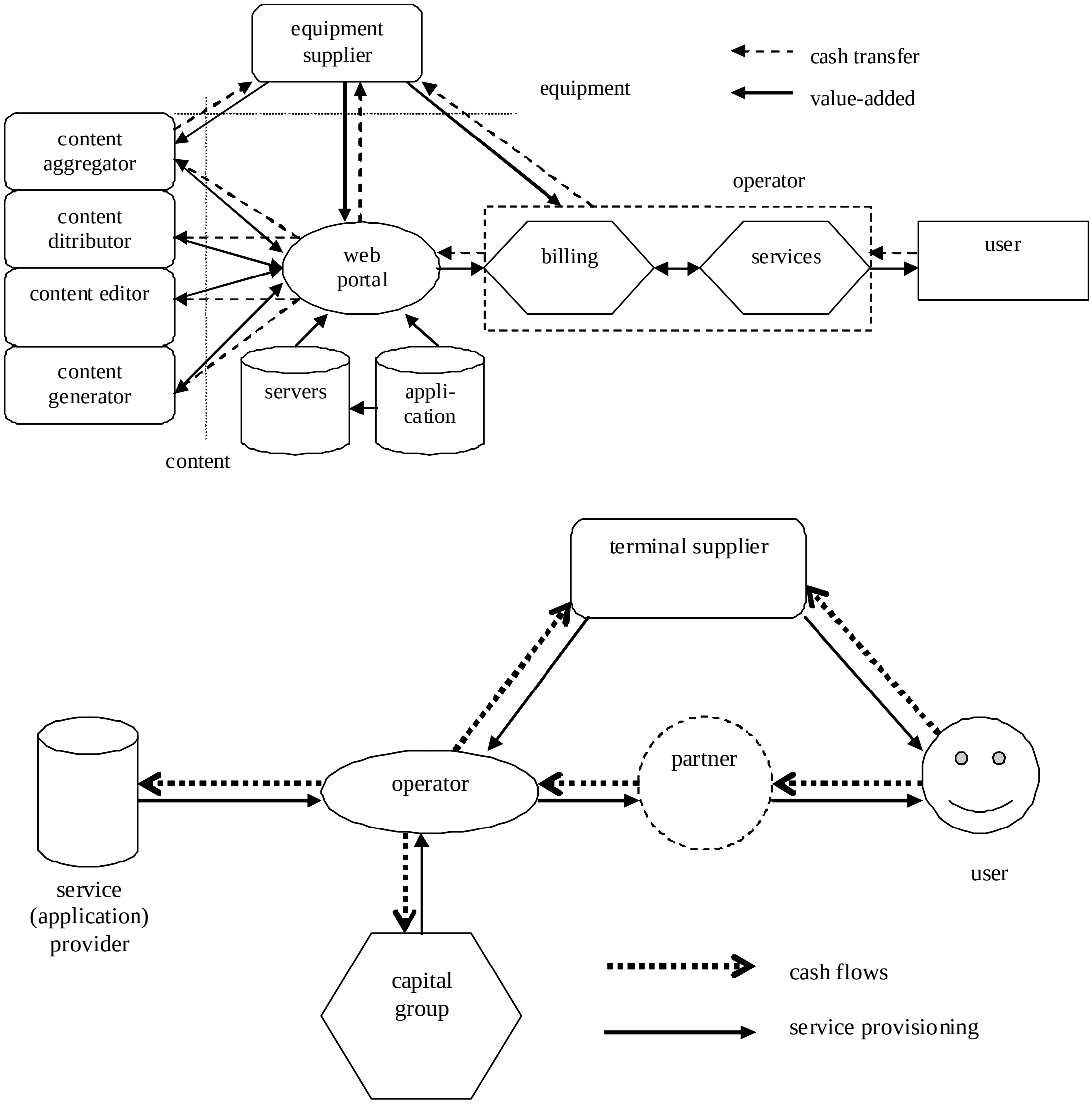

Figure 2 relation between entities in PPDR

The overall vision of the whole supply chain of the different entities defined above is shown in ***Figure 3***.

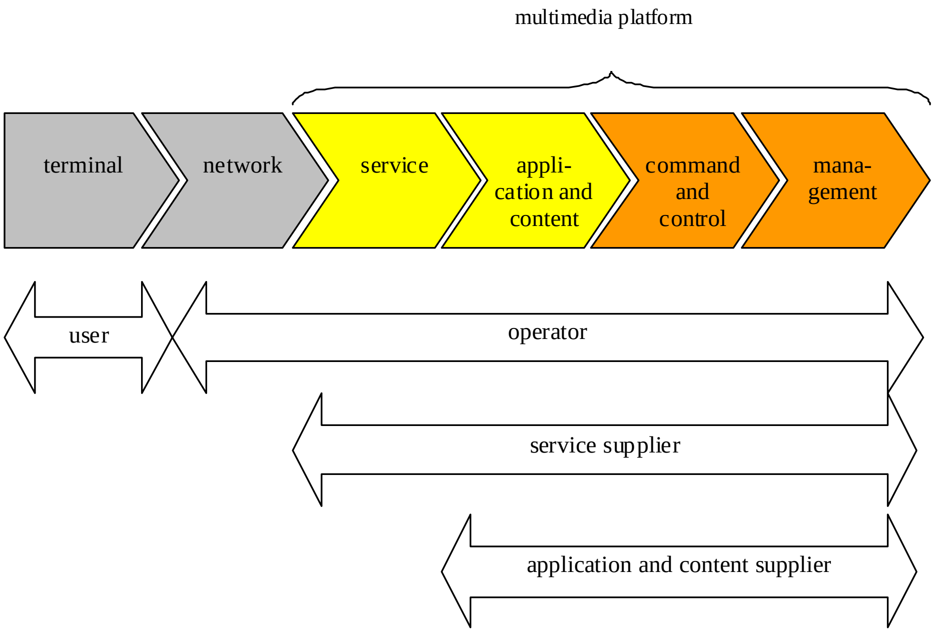

Figure 3 PPDR supply chain

3.3 Trends

The literature survey indicates certain business trends in constructing and running communication systems, e.g.:

- shorter supplier chain – most of service elements are delivered by the operator,
- division of an operator into separate specialized entities (closely cooperating),
- cooperation with many external suppliers,
- convergence – integrating different networks, services, operators, etc. within one service package over which a dedicated control application is built,
- diversification in the offerings that allows minimizing costs or maximizing QoS and functionality.

These trends will be taken into account when studying the RESCUE project impact on the public safety market.

4. PPDR Systems Life cycle

PPDR communications systems are required to respond to critical missions where security, availability, robustness and resilience are required under the most stringent conditions (e.g, high mobility, degradation or absence of infrastructures). Since most commercial solutions do not meet mission critical requirements, PPDR organisations rely on dedicated bespoke products over long life cycles (more than 10 years). Therefore, decision-makers need to understand the several elements involved in deploying and managing these systems.

This section presents a high-level overview of a PPDR system's life cycle typically followed, in part of in full, by PPDR organisations. It is based on the System Life Cycle Planning Guide [ITU1] published by the U.S. Department of Homeland Security, complemented with additional references from European sources and EC Directives.

4.1 Overview

The PPDR systems life cycle is presented in ***Figure 4*** and is described next.

Figure 4 PPDR Systems Life Cycle

The life cycle takes into consideration existing relevant emergency communications lifecycle planning documents as well as industry best practices for life cycle planning methodologies, such as Closed Loop Life-cycle Planning, System Development Life-cycle, and Technology Life-cycle Management [5]

4.2 Step 1: Planning

This step is concerned with the establishment of the planning team. This team is in charge to define a solid plan (considering the complete PPDR systems life cycle) and document the operational and technical requirements to support system replacement or upgrade. At this stage, PPDR organisations might conduct pre-procurement actions and experiments involving potential candidate technologies to define feasible and fully representative requirements that better meet the needs of the organisation(s). Also important is to consider interoperability aspects and possible infrastructure sharing between and among departments and organisations (in the homeland and cross-border).

4.3 Step 2: Acquisition

This step focuses on the acquisition of a new PPDR system. Following best practices, a Request for Proposal (RfP) is developed and potential suppliers are invited to bid. It is important to clearly define key-requirements that are specific for PPDR, that is, mission critical and security operations.
The RfP may be supported by a pre-procurement stage as shown in the example of ***Figure 5***.

Figure 5 an example of UK public procurement process

The financial aspects should consider the Total Cost of Ownership (TCO) that includes:

- Migration option (smooth or radical)
- Cost elements:
  - Equipment: site equipment (base stations, antenna, power); leased backhaul services (if provided by commercial carriers); subscriber/client terminals (PMR); management consoles and system interfaces.
  - Recurring costs: infrastructure, subscriber, rentals/fees, training, maintenance.
- Interoperability costs.

Furthermore, the proper purchasing option identified in section 6 should be selected as well as the investment financial strategies. This step finalises with the system contract.

4.4 Step 3: Implementation

In this stage, the system is ordered, installed and tested. In the case of novel systems, a thorough test phase is often set to ensure it performs as required, starting from a small scale deployment until it reaches full system scale.
A training plan for the new system is required including all end-users and support staff. Training should include:

- Operational aspects, including first-responders and communications operators.
- Technical aspects, including maintenance and system management.
- Interoperability aspects, where applicable, involve other departments and organisations during the migration phase and assess all interoperability issues.

This stage finalises with the system being accepted.

4.5 Step 4: Support and Maintenance

Duration: 10-15 years, depending on the system life
In this stage, the users receive assistance and support to operate and functon with the system. System support options can be as follows: vendor support (provided by the supplier); third-party support (provided by a third-party local service) and internal support (provided by in-house staff).
A maintenance plan should be set considering:

- A warranty period - negotiated period during which the vendor is required to support the system - that is supported by the vendor.
- Long term maintenance to ensure coverage in case of equipment breakage and malfunctions. It should also include maintenance of software (e.g., version upgrades).

In addition, the existing Standard Operating Procedures - i.e., documents that govern all areas of an organisation's mission - should be reviewed and updated to exploit new capabilities brought by the new system.

4.6 Step 5: Refreshment and Upgrade

Duration: 10-15 years, depending on the system life
This step ensures that the system will continue to support the end-users needs over its lifetime. It consists in incremental updates that might improve the system as a result of, e.g., new end-users requirements and needs, new standards and new interoperability requirements.

4.7 Step 6: Disposition and retirement

This stage deals with the disposition of the system in a way that is graceful (i.e. without affecting operations) and safe (i.e., harmless to the environment).
The following is considered:

- Reuse: keep all components that can have extended life value and could be reused with the new system (without compromising performance, reliability and/or security).
- Repurpose: deliver equipment to departments or service units that would otherwise not qualify for operating on the new system, but might benefit from any residual life of the old system.
- Space availability and costs: assess the available space to host both old and new systems. Furthermore, take into account costs to maintain both systems.

Additionally, disposal of equipment should consider a "cradle-to-cradle" policy for a sustainable use of natural resources (COM(2003)572 adopted by the Commission on 1st October 2003 [ECC03]). All hazardous material (e.g., batteries) should be properly disposed according to the Directive 2002/96/EC (Waste Electrical and Electronic Equipment Directive [EP03]).
This section will helped estimating global costs of a PPDR system over its complete life cycle from the end-users perspective. An estimate of cost can be derived from each step (beyond simple equipment purchase). Furthermore, options such as 'smooth' and 'radical' migration should be considered when proposing upgrades.

5. RESCUE Promising Impact on Tomorrow's PPDR Deployments

After thoroughly describing the current technologies and services used in PPDR systems, as well as the markets status and evolutions we focus hereafter tends to impact the public safety area.

The RESCUE project promises to exploit the links-on-the-fly concept in order to offer reliable communications over lossy links. In practice, several reasons may force rescuers to operate in lossy conditions. Indeed, a major objective of the implementation phase is to study, dimension and plan the deployment of the PPDR network. It is clear that this phase is highly dependent on the deployment region characteristics such as the size, property (rural or urban), interoperability issues, expected density etc… (refer to the numbers in the ***Figure 6*** below). Because the infrastructure availability and resilience constitute an essential requirement of the PPDR network, TETRA planning often considers redundancy in the deployed base stations in order to face such situations. Moreover mobile base stations can be deployed for additional communication opportunities in specific regions.

Country	Area sq. km	Inh. mill.	Inh./ sq.km	# TETRA BS	Inh./TETRA BS
Netherlands	41.000	16,8	404	510	33.000
Denmark	43.000	5,5	128	500	11.000
Belgium	31.000	10,4	335	580	18.000
Norway	324.000	5	15,6	2.100	2.400
Finland	338.000	5,4	16	1.350	4.000
Sweden	449.000	9	20	1.800	5.000
France	549.000	65	118	1400+500	34.200
UK	244.000	61	250	3.500	17.400
Germany	357.000	82	230	4.400	18.600

Figure 6 PPDR deployments in European Countries

However, lossy links can still be observed in the particular case of a partially destroyed infrastructure. Indeed, following a big catastrophe such as a major earthquake, many TETRA base stations can collapse rendering a disconnected network. In such situations deploying, mobile relays cannot be envisaged due to accessibility issues and the extent of the damaged infrastructure.
The RESCUE project targets essentially these type of scenarios by proposing cost effective solutions for broadband services and communications in damaged PPDR networks.

5.1 Required changes

Exploiting the links-on-the-fly concepts is completely agnostic to the deployed technology. In fact, RESCUE is based on an innovative coding technique that is able to exploit received information although corrupted from different sources. More generally, the RESCUE paradigm is based on combining multiple copies of the same information received from multiple sources. The correlation between these different copies of the same corrupted information enables us to recover the initially sent information. To do so, our solution empowers nodes with two main features:

- Nodes relay corrupted information and do not discard them as it is the case in traditional networks.
- Many routes can be used to send the same information from a source to a destination

Describing technical details of the RESCUE link-of-the-fly concepts and its exploitation in the public safety concept is outside the scope of this project. Please refer to the project technical deliverables for more information.

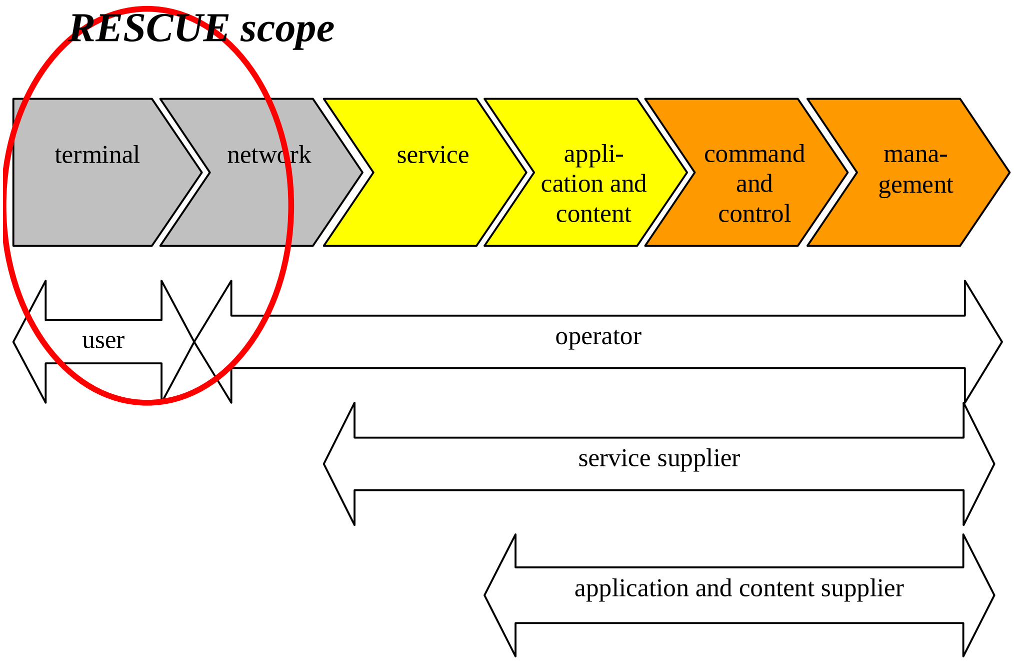

Figure 7 RESCUE required changes for PPDR deployment

In order to operate, the solutions proposed within the RESCUE project necessitate changes at the terminal level and at the base stations of PPDR operators. Indeed, empowering terminals with the capability of capturing corrupted information then relaying them through different routes constitute the main required changes. Base stations should also be capable of correlating received signals in order to decode the initially sent information.

5.1.1 On the terminal side

It is commonly accepted that the recent evolutions in the area of mobile communications shall directly impact the public safety area. In particular, the increasing computing and communicating capabilities of end user devices is promised to create numerous new opportunities and applications for PPDR. This new generation of terminals is empowered with multiple wireless interfaces, smartphone like computing capabilities and can easily integrated in a full-IP PMR solution. For instance, Thales has launched recently it is first PMR services over LTE. This innovation breakthrough is mainly enabled by the THALES TESQUAD smartphone [TESQUAD] a multi-band, ruggedized, Android based smartphone (***Figure 8***).

Therefore, exploiting the multi-band capability to transmit at different bands and essentially to force the reception of corrupted information is possible in tomorrow's PPDR terminals. In practice, the RESCUE operations require software upgrades at the end device level with limited changes at the hardware level. Moreover, in order to make RESCUE algorithms operate properly, enabling the device to device mode is required. This type of direct communication between devices is already possible in TETRA solutions and under thorough investigation in the LTE standardisation for public safety. However, RESCUE requires device-to-device communications spreading across multiple nodes thus creating a multi-hop network. Still, these changes are feasible in software in today's devices.

More generally, for investigating the RESCUE efficiency in a public safety network, the following requirements need to be gathered:

- Software upgrades at the physical, MAC and routing layers are required
- To maximize the efficiency of the solution, a high number of rescuers terminals should integrate RESCUE algorithm.
- The robustness and the reliability of any PPDR solution is the main issue. The solution should be thoroughly tested in different network conditions
- Backward compatibility is also a major issue in critical communication areas. Consequently, RESCUE nodes should be able to operate with legacy PMR solutions.

Figure 8 THALES TESQUAD terminals

5.1.2 On the base station side

In addition to the software updates at the terminal level, implementing the RESCUE solution in an operator PPDR infrastructure requires modifications at the base station level. Recall that RESCUE is based on receiving multiple copies of corrupted information then correlating them in order to recover the original message. From a base station perspective, such mechanisms require the following changes:

1) the base stations maintains multiple route to each node
2) the base station captures all received signal on different channels even corrupted ones and stores them in a dedicated buffer
3) the base stations implements the decoding algorithm designed within the RESCUE project in order to recover sent information from multiple corrupted copies.

In practice, integrating changes in operators' base stations is considered more challenging than simply changing the users terminals. However, the RESCUE paradigm proposes enhancements mainly at the air-interface level with upgrades at the MAC and the routing level. The proposed changes do not impact the connection of the base stations to the backbone of the PPDR operators. Most likely, the network and its costly equipment shall remain unchanged.

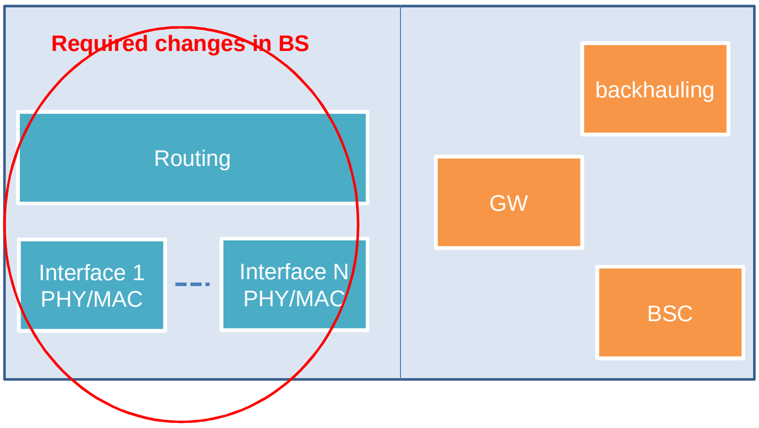

Figure 9 RESCUE changes in the base station architecture

In contrast with the changes at the terminal level, evolving to RESCUE based PPDR solution will require hardware and software upgrades (***Figure 9***). As the hardware level, PPDR base stations today exploit a single wireless technology, namely TETRA or LTE based for the latest deployments. In order to take the maximum advantages our project can offer, empowering the base station with multiple wireless technologies is necessary. Indeed, exploiting the diversity on different frequencies in order to convey the information to the base station seems necessary for the efficiency of our solution. Deploying a multihomed infrastructure capable to support different wireless technologies is possible today. Such solutions will rely on virtualization techniques already largely investigated by public mobile operators.

At the software level, upgrades are required at the base station level to embed the correlation technique (decoding algorithm), and the multi-path routing protocol.

In summary, implementing RESCUE solution requires non negligible hardware and software changes at the base station level. Nevertheless, these improvements are possible today with the widespread of virtualization techniques and their use in similar civil configurations. Moreover changes remain within the base station scope and do not require any modifications in the operators' backbone where any intervention can be very expensive.

5.2 Exploitation in operational PPDR network

The solution we propose with the RESCUE project targets public safety networks during relief operations. To increase their efficiency PPDR networks are usually highly hierarchical and implicate a high number of rescuers. As highlighted in ***Figure 10***, a connection to a command and control center (CCC) that coordinates the rescue operation is necessary. Besides, a set of dedicated applications and applications are offered within these network; for more information about PPDR deployments and required services please refer to RESCUE D1.1 deliverable [RD1.1].

In a fully operational PMR network, exploiting the breakthrough enabled by the RESCUE project can reduce deployment costs. Indeed, tolerating and decoding corrupted signal arriving from nodes outside the classically defined transmission/reception range of the base station (base station cell) can create a connected network with less deployed base stations. More precisely, device to device communications and multiple routes communications are key features in the RESCUE envisaged solutions. These two techniques enable a coverage extension without the need for deploying additional base stations. Consequently, they allow the same service for the same number of users with less deployed infrastructure, in other words with reduced costs. In brief, dimensioning a RESCUE based different needs to consider the lossy links exploitation for communication during the planning phase. This results in a PPDR network with a lower number of required based stations.

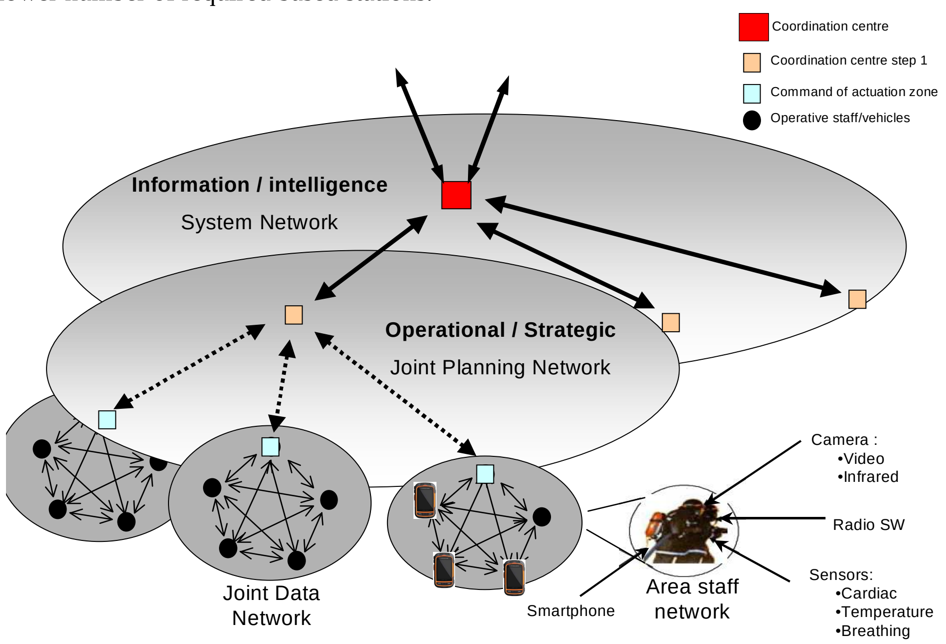

Figure 10 A typical PPDR network deployment

Nevertheless, from our preliminary studies in this project we believe that for the efficiency of our solution, a dense network is preferred. RESCUE requires high diversity in terms of links and routes between nodes for satisfactory results. Based on previous observations one can conclude that the performance of RESCUE will be highly dependent on the environment in which it will be implemented and the number of operating rescuers within the relief zone. Intuitively, we believe that such solutions will offer its highest efficiency in dense urban areas with a high number of operating staff. The conducted work in the coming years of this project will allow to better characterizing the solutions performance and comparing different deployment environment.

5.3 RESCUE in partially destroyed infrastructure

The RESCUE project brings forth a communication technology design targeted for largely unplanned multi-hop or mesh networks that are further subject to dynamic topology changes. Such situation occurs When following a major catastrophe the infrastructure is sparse or partially damaged. Unfortunately, such scenarios are very likely to happen in public safety networks, but surprisingly they are very often not considered in the PPDR deployments. The solutions we propose in the RESCUE project target essentially these situations thus offering communication opportunities and bandwidth for deployed rescue teams. More precisely, we focus on a partially destroyed infrastructure shown in ***Figure 11***. Our use case comprises a diversity of wireless links; please refer for RESCUE D1.1 deliverable for more details.

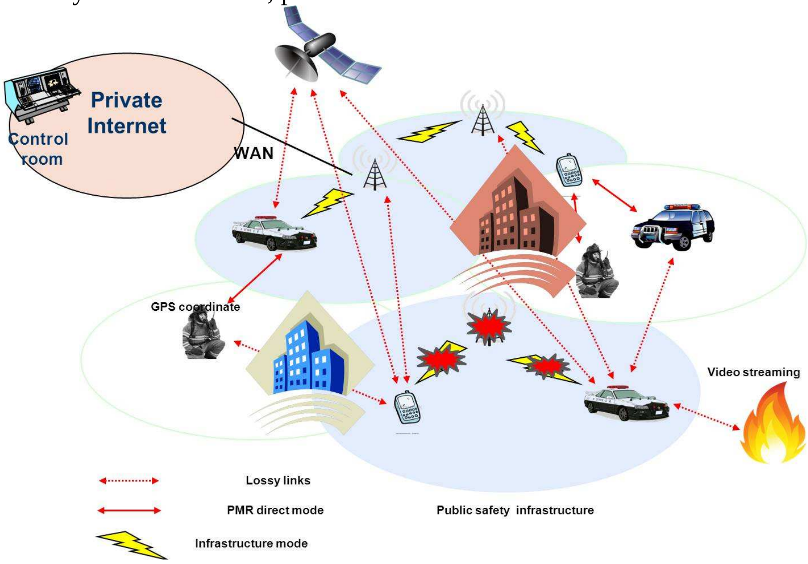

Figure 11 A studied public safety use case in the RESCUE project

The availability and the resilience of PPDR infrastructures are indeed key issues in the success relief operations. The dilemma is that the more the event is big and localized, the more communication resources are required within this specific location. As a matter of fact, the planned and deployed redundancy encounters the same level of destruction. For these reasons, PPDR operators usually adopt deployable solutions that can be reactively set up on the fly in case of a network collapse. The most common solution is the mobile base stations carried by dedicated trucks that ensure their autonomy in terms of power supply.

However, deployable base stations have also drawbacks particularly when the relief operation is taking place in a difficult to access area. This can be the case when routes are damaged for instance following a major earthquake or in case of big forest fires. For these reasons deploying fast communication capabilities for rescuers and first responders is still an open area for new and innovative initiatives. In this specific domain, the European commission has recently funded the ABSOLUTE project [ABS12] that proposed an opportunistic combination of aerial, terrestrial and satellite communication links with the aim to maximize network availability and allow a rapid and incremental network deployment. In fact, the ABSOLUTE approach is LTE driven and relies on the deployment of aerial LTE eNodeB.

In the RESCUE project we target the problem from a different angle. In order to cater for the new mission critical services with very high throughput and low-delay requirements during the immediate post-emergency period, we exploit the partially destroyed infrastructure and the diversity of technologies, devices, and users it comprises. Unlike other solutions, RESCUE does not rely on deployable communication resources but in contrast uses lossy links , multi-hop and multiple routes to maintain a connected network. By taking advantage of the link-on-the-fly concept, we are able to offer communication opportunities in a cost efficient manner. As described earlier, our solution requires only limited modification in the rescuers terminals and in the base stations.

6. Security Issues

In addition to the resilience of the implemented infrastructure, dealing with the security of communications is a major issue to consider when dealing with public safety infrastructures. Due to the nature of the conveyed information and the need for their timely delivery, 3 main security services need to be ensured by the communication platform:

- **Authentication:** refers to the capability of receivers of attesting the exact identity of the sender of information. One can easily notice that during a relief operation, verifying the identity thus the validity of received of messages is of a high priority. Indeed, communications between group of rescuers as well as orders/updates sent from/to command and control centre (CCC) need to be verified for the proper course of the relief operation.
- **Data integrity:** In addition to identifying the issuer of the information without ambiguity, however verifying that the enclosed data was not modified intentionally or not is also necessary in PPDR networks. In fact, being sure that received orders and updates were not altered enables all participants in the mission to operate quickly without the need for additional validation of the information
- **Confidentiality:** refers to the capability of a communication medium of not divulgating the exchanged information to a third party. In PPDR infrastructures, such mechanisms based on data encryption can be required by some users a.k.a police forces. However, in many cases the exchanged messages are by no means confidential since they constitute public orders or communications between rescuers or even group of rescuers. Moreover, in some cases exchanged clear information (not encrypted) can help cooperation between teams by allowing relative compatibility. Still, confidential mode is a basic requirement in PPDR systems for public safety operations.

The core of RESCUE paradigm relies on exchanging partially corrupted information through a variety of routes between an emitter and a receiver. Therefore, verifying the identity of the sender and the integrity of erroneous data can be seen as a challenging task. Several options can be considered to overcome these problems. One can think that the final destination after correlating all the received copies of a message can conduct the authentication and integrity checks.
However, relaying blindly the received signals at the intermediate nodes without being able to check the origin and the validity of the information can have a negative impact on the network throughput and capacity. In this case malicious nodes can inject corrupted information that even dropped at the destination can affect the service observed by the rescuers.

RESCUE's links-on-the-fly principle and its exploitation in partially destroyed network constitute a very innovative technology. These mechanisms have a very low TRL hence the RESCUE project is one of the first initiative towards pushing these concepts into maturity. From an industrial perspective, investigating thoroughly security issues in a PPDR communication system is an essential step in the marketing strategy of vendors and operators. Although security is outside the scope of this project it will be implicitly considered when proposing solutions and algorithms for the public safety use cases.

7. Relevance to Public Safety Stakeholders' Roadmaps

Influenced by the fast occurring changes in the mobile communication and networking areas, the public safety communication domain is taking advantage of these quick evolutions. During the past decades numerous factors have contributed to increasing the gap between technological breakthroughs in the mobile communication world and PPDR. While LTE 4G is already largely deployed in several countries, most of PPDR solutions are still mostly relying on TETRA standard thus offering mainly voice services, with at best narrowband data capabilities. Quite obviously, the PMR area is today at the edge of a significant shift.

7.1 Expected evolutions

The reasons for the slow evolution of the public safety market are numerous and can be summarized as follows:

- **Strong requirements in terms of reliability, availability and security:** As earlier precised in this deliverable, public safety area has very strict requirements in terms of call success rate and quality of experience. Guaranteeing these requirements require additional delays for adopting novel technologies.

- **Relatively low needs in terms of capacity:** Until recently offering voice communications with narrowband and limited data exchange capabilities were considered sufficient for basic relief tasks. Driven by the emergence of highly powerful devices and hundreds of innovative applications an increasing demand for high datarates in public safety operations is observed. Obviously, exchanging maps, videos, images or even chats can help rescuers save lives during rescue operations
- **Economic reasons in developed countries:** As stated earlier, the life cycle of a mobile infrastructure until its retirement is somehow a well-defined procedure. Migrating towards a new technology is often a long and expensive task. This process is even more complex if it depends on a government decision that takes much longer times and can be delayed by the changes in governing bodies. Moreover, with budget and cost reductions due to latest economic crisis, changing a fully operational infrastructure is a decision difficult to defend.
- **Relatively complex standardization process:** As per today, the TETRA standard remains the de facto standard for public safety communications. Things have started to move recently in ETSI 3GPP bodies, with the objective of enhancing LTE standards in order to meet public safety requirements. Two main features are necessary for PPDR namely proximity services (device to device) and group communications. Efforts started in the release 11 and are underway in Release 12 of LTE standards [3GPP]. The objective is to offer within the LTE standards with features such as proximity services and group communications in order to address public safety requirements in a high data rate and multimedia capable network.

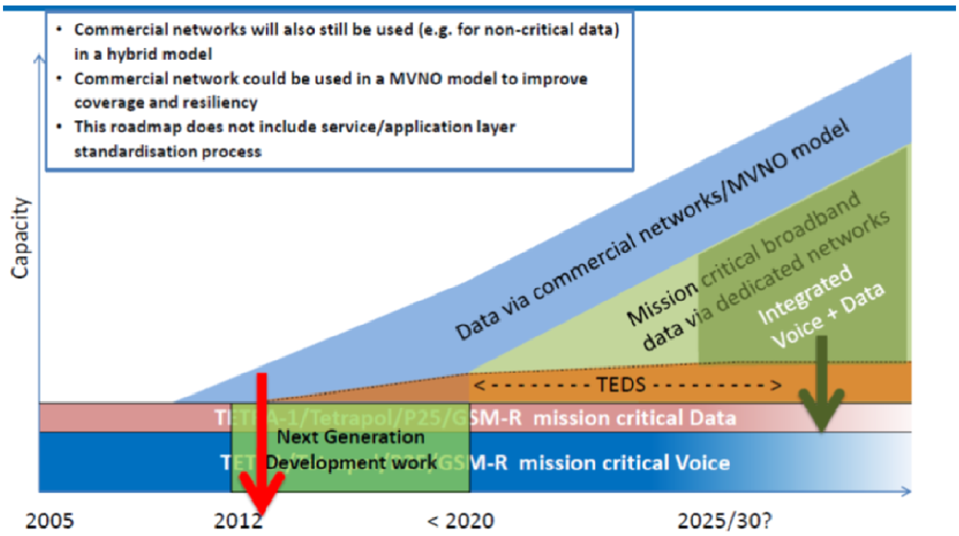

Figure 12 TETRA and Critical Communications Association TCCA Broadband systems Roadmap

In the meanwhile, due to the complexity and the long expected delays for establishing new dedicated broadband PPDR networks, TETRA and Critical Communications Association (TCCA) is predicting the emergence of new models for public safety operators (***Figure 12***). Some of these solutions are already deployed today. In practice, exploiting commercial networks/infrastructure can reduce the cost and the time required for public safety operators to have a dedicated high capacity and broadband network. Relying on a third party for public safety can take different forms.

1- An existing private operator can open part of its infrastructure for PPDR users. Such option means that this commercial operator through a contract with special authorities guarantees special treatment and high reliability for PPDR users over its network
2- An intermediate entity can play the role of a virtual operator for public safety users. In this scenario, the virtual operator can exploit the resources from different commercial operators for offering a dedicated service for rescuers. The virtual operators is tied by special contracts with many commercial operators then equips with special SIM cards PPDR users. In other words, MVNOs hide the physical networks to end users by allowing them to exploit transparently a set of existing operators' infrastructures.

In summary, before the public safety standardisation process at the 3GPP reaches deployment phases it is expected that broadband and high data rates will be offered for PPDR through commercial or virtual operators. In most cases, these networks will also rely on the LTE technology.

7.2 RESCUE expected impacts

Based on previous discussions, it is clear that the future of PPDR communication systems will be tightly linked to the LTE technology and its public safety extensions. Therefore investigating RESCUE project impact on tomorrow's public safety solutions can be seen as RESCUE's potential compatibility with LTE technology and its public safety features and evolutions. Since the proposed solutions in this project have a low TRL (less than 4), their impact on industry is rather a long term issue. The roadmap to achieving these objectives by Thales starts by integrating RESCUE algorithms in the proximity services proposed by LTE to reach a standalone heterogeneous solution. These steps can be summarized as follows:

1- Include in release 12 public safety constraints, proximity services and group communications

With all the advantage LTE offers, public safety actors are trying to exploit this momentum to enrich the specifications with public safety related issues. In fact, Thales Communications & Security with his strategic objective of increasing his market shares in the public safety domain is taking a very active part in the public safety discussions in 3GPP. In particular, Thales teams are following closely the on-going work in Release 12 of 3GPP LTE standards in order to enhance LTE to meet public safety application requirements. These efforts lead to defining 3 approved work items (WI) in which Thales is contributing. The shortest term objectives are to include proximity services (PMR terminology for device to device communication) as well as group communications. The LTE release 12 which is planned for freezing mid-2014 already includes many feasibility studies and technical reports that pave the way for providing broadband for public safety networks.

2- Empower direct mode with new advanced coding techniques (longer term)

On a longer term, Thales objective is to enhance the efficiency and the performance of the direct mode and group communication schemes. It is of a common knowledge that ensuring multi-hop communications is a challenging task in wireless networks in general. Therefore, Thales targets to explore advanced coding and physical layer solutions to allow better diversity and spatial reuse. The lossy distributed coding investigated in RESCUE is part of these coding solutions. Hence, Thales then plans to integrate in its public safety products coding techniques studied and validated in RESCUE for more efficient direct mode communications in public safety networks. More specifically, such coding techniques need to be compatible with the LTE standard at this level to investigate products development. The goal will be to reduce the cost of infrastructure deployment and increase its resilience by allowing multi-hop relaying. Note that the terminal migration is not an issue since major modifications will be done in software.

3- Evolve to a full integrated solutions for different public safety technologies

On a more longer term Thales envisions an integrated public safety solution that includes different types of communications means in public safety today. Such solution will comprise PPDR communications, satellites, sensors actuators and any other communication mode exploited by PDDR workers. All these information exchange should be standardized and interfaces well specified. Such vision is totally compatible with the RESCUE project. In fact, using different lossy links from different technologies to allow robust information exchange is the main problem targeted by RESCUE. From a strategic point of view Thales believes that exploiting the momentum of cooperative projects and the funding proposed by the EU, for exploring new paradigms with low TRL is essential in optimising the time to market of its new products. Hence, Thales interest and participation in the RESCUE project.

8. Conclusion

There is no doubt today that the public safety market is at the edge of a major shift. These changes will most likely take advantage of the tremendous efforts already spent in the LTE ecosystems and their capacity to offer broadband communications and multimedia services. However, PPDR systems have special requirements that require to go beyond current LTE solutions and standards. Namely, supporting device to device communications and group calls are essential requirements for relief operations. 3GPP in the coming release 12 of LTE is starting to consider these particular constraints for public safety. Nevertheless the way is still long to reaching final solutions and most importantly the room for new innovative mechanism is still available.

The solutions explored in the RESCUE project constitute a family of options that can impact the future of PMR communications. This project is based on a novel coding scheme that is capable to restore data from multiple copies of corrupted information. More precisely, in order to receive multiple copies of the same information and decode them, the RESCUE paradigm requires changes not only at the physical but also at the MAC and routing layers in order to establish multi-route communications. It also relies of the capability of terminals to act as relays for other devices i.e. device-to-device communications.

The potential of RESCUE resides in its capacity to offer communication services with fewer infrastructures than classical PMR solutions. Indeed, it is commonly admitted that relaying information at the device level and creating multi-hop networks can increase the coverage and the capacity of deployed networks. Similarly, for a particular deployment in a coverage area these techniques can offer the same capacity with less deployed infrastructure. This observation is particularly interesting in PPDR where during a catastrophe part of the operator infrastructure can collapse. In these situations, RESCUE promises to guarantee uninterrupted connectivity and communications through clever coding and relaying techniques.

In this document we have comprehensively explored the PPDR systems and investigated how RESCUE project can impact the evolution in this area. We have conducted our study from an operator and terminal manufacturer point of view (i.e perspective of Thales) highlighting the high potential of RESCUE in this challenging domain. Still the success of this project and obtained results during this collaboration is an essential condition for pushing towards exploiting its outcome in tomorrow's public safety products.

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