



Security And Interoperability in Next Generation PPDR
Communication Infrastructures



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SALUS Techno-Economic Analysis Tool

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Abstract: Deliverable 4.1 describes the SALUS techno-economic analysis tool, a tool where different migration scenarios are considered (in terms of both network and PPDR service evolution).

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EXECUTIVE SUMMARY

The main objective of this document is to present the SALUS techno-economic tool (SALUS TE tool) taking into account the three proposed SALUS use cases discussed in WP2 (City Security- Public order demonstration or riot; Temporary Protection - Olympic-style sporting event and; Disaster Recovery- Heavy flooding due to prolonged periods of rain). These use cases will be used to address the needs of the Public Protection and Disaster Relief (PPDR) user community as they migrate into the next generation PPDR networks with increasing data needs and multimedia capabilities.

In order to accurately estimate and assess the investments and deployments that are required in terms of new technologies (e.g. LTE, Wi-Fi and video surveillance), the CAPEX and OPEX indexes are required to be studied. Following this approach, this deliverable presents the SALUS TE tool that has been implemented both as a standalone application and as a Web based application. The SALUS TE tool takes into account input parameters associated with LTE dimensioning in terms of BS and EPC core, Wi-Fi access-point, number of surveillance point-of-interest depending on the use-case scenarios, the coverage area per surveillance point-of-interest and their interworking with existing TETRA and TETRAPOL system. As an output, the TE tool determines the CAPEX, OPEX and Total Cost of Ownership (TCO) indexes for a period of pre-defined number of years.

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1 INTRODUCTION

Public Protection and Disaster Relief (PPDR) agencies in EC member states are relying on digital Private Mobile Radio (PMR) networks for mission-critical voice and data communication. These networks are highly resilient and properly dimensioned to cope with crisis and emergency handling, and are well protected against monitoring and intrusion by means of encryption, authentication and integrity. The two main standards for digital PMR networks for PPDR in Europe are TETRA (TERrestrial Trunked RAdio) and TETRAPOL. These networks provide a secure and resilient mobile voice and data infrastructure. Besides they have features matched to the special requirements of PPDR, including broadcast, dynamic secure groups, push to talk, call priority and secure roaming.

The main goal of SALUS is to design, implement and evaluate a next generation communication network for Public Protection and Disaster Relief (PPDR) agencies, supported by network operators and industry, using novel technologies such as LTE, Wi-Fi and surveillance cameras. Within the context of SALUS, next generation PPDR systems will be designed and developed. SALUS will consider not only the deployment of the aforementioned technologies, but also their interworking with existing TETRA and TETRAPOL systems.

Apart from the technological advances, it is important to consider techno-economic factors towards the adoption of the new technologies for next generation PPDR systems. Towards this direction, a techno-economic tool has been designed and developed that aims to assist the design and development of such networks, also considering the impact of cost. The SALUS Techno-Economic tool has been implemented as a Web-based application. Another version exists that runs on the Octave platform. The SALUS Techno-Economic tool calculates both CAPEX and OPEX indexes in order to efficiently estimate whether the deployment of certain particular technologies of next generation PPDR communication networks and their implementation (based on a specific market analysis) is efficient and profitable for the several organizations.

2 USE CASES AND SCENARIOS

The SALUS TE tool was designed and developed taking in consideration the three SALUS use cases defined in deliverable 2.1 [1]

- *City Security* use case: refers to the management of a public disorder event with permanently deployed PPDR infrastructure in a city location. It identifies the services used and the technologies and suppliers that the PPDR end users are reliant upon, and how the availability of these services is impacted upon by a significant security Incident in the city.
- *Temporary Protection* use case: refers to an event of considerable size, in a sports arena, lasting several days, where a public disorder situation is dealt with the usage of permanent and temporary PPDR infrastructure. The interoperation of technologies such as Wi-Fi, LTE, BAN and PMR narrowband are required. The proper continuation of services for Public Safety is crucial.
- *Disaster Recovery*: refers to the case where a significant man-made or natural disaster (such as flooding etc.) has rendered several networks (power, communication etc.) unusable. The PPDR infrastructure should be based on transportable and rapidly deployable solutions so that voice, video and data services can be quickly restored for Rescue teams. The environmental conditions may be considered severe and hostile. This use case also illustrates a cross-border operation with interoperability requirements.

3 FUTURE PPDR DEPLOYMENT MODELS

3.1 Possible LTE services deployment models

Three main models can be adopted by PPDR organisations to deploy new (broadband) services:

- Subscribe to the data services of commercial mobile network operator (MNO),
- Develop a Mobile Virtual Network Operator (MVNO) approach to offer better controlled and secured access to PPDR services to end-users,
- Deploy, maintain and operate a dedicated PPDR broadband network offering new services and applications.

Each model offers different level of services to the PPDR user community and also requires different level of investment and recurring costs.

Table 1: Main deployment models for PPDR broadband services

Deployment Model	CAPEX	OPEX
MNO	Devices (incl. specific installation –e.g. in-car-) PPDR Applications Gateway to narrow-band PPDR networks	Monthly subscription fee Device maintenance (if any)
MVNO	Devices PPDR applications, LTE Network elements (HSS, PCRF, P-GW) Security Gateway, Gateway to narrow-band PPDR networks	Global volume of data fee (per operator) Device maintenance MVNO operations
Dedicated network	Devices, LTE network (RAN and EPC) Backhaul (if owned) Wi-Fi ad hoc networks Security Gateway, Gateway to narrow-band PPDR networks One-time spectrum license fee	Network operations Network equipment maintenance Annual spectrum license fee Backhaul fee (if relevant)

It is to be noted that a PPDR organisation may decide also to apply a mix of the models (e.g. a combination of dedicated networks and MNO) or to apply different models over time. The models, their merits and their roadmap will be further developed in future deliverables of WP4 (D4.3, D4.6 and D4.9).

Out of the three models, the third one is indeed the most challenging in terms of deployment. Next section provides high level information of the main dimensioning parameters and options that will affect the total cost of ownership of a dedicated LTE system for PPDR organisations.

3.2 LTE system dimensioning considerations

The dimensioning and design of a dedicated LTE network plays a major role in the trade-off between the cost deploying, maintaining and operating and the offered services and availability to PPDR users. The cost of the network is influenced by two main elements:

- The radio access network design,
- The architecture design.

These elements are further discussed in the following subsections. Besides, devices are also one of the main elements impacting the cost to provide new services. Indeed, the different devices (e.g. simple handled, smartphone, tablet, vehicular router...) that will be used in future PPDR operations will provide different services but will also have different cost models.

It is to be noted that in the current version of the tool, the quantities of network equipment are user inputs. Hence following subsections are intended to explain the parameters that will guide the user's inputs and to provide possible evolutions of the SALUS TE tool for the automated generation of meaningful equipment bill of quantities.

3.2.1 LTE Radio Access Network design

Actual dimensioning of a radio access network is a complex task that usually requires sophisticated tools taking into account a large number of parameters covering multiple aspects such as:

- Coverage area target,
- Capacity target,
- Spectrum and channel bandwidth,
- Product performances,
- Availability and selection of radio site,
- User density and traffic profiles,
- amongst others.

Although the SALUS TE tool will not require as many parameters as an operational radio network engineering tool, it may need to take into account a number of input parameters that significantly influence the resulting radio network design since ultimately, a significant portion of the cost of deployment and operations of a wireless network is related to the number of sites needed to provide the required services in the target service area. These parameters are

- Coverage area and site configurations,
- Radio system parameters,
- Services and user profiles.

Based on these parameters, typical coverage values can be generated and used as internal look-up table for the tool. This provides the minimum number of base stations to cover a given service area (coverage limited scenario). Adding the capacity requirements to the model allows verifying if additional site need to be deployed to cope with the target capacity.

3.2.1.1 Coverage area and site configurations

The type of environment (urban, rural...) where the radio system is deployed has a significant impact on the coverage that can be reached by a radio site. It is proposed to model the target coverage area by a limited set of typical environments associated with their respective overall surface.

It is a common practice for a simplified radio network design to define a default site configuration for every typical environment. This consists in associating a default base station antenna height and a base station configuration (omnidirectional or tri-sector site) that is in average relevant for each type of environment.

Coverage availability target are also associated to each environment of the service area. In public safety, a commonly used parameter is the coverage probability at cell edge (note – it is also possible to use the cell coverage probability area). And, to compute the resulting margin to

be applied on the link budget, the standard deviation of the shadowing effect needs to be provided.

Finally, for each environment, a relevant input parameter is whether there is a need to provide the service in indoor or in outdoor only. The following table summarizes the proposed environment and default site configuration and values that can be used to generate a simple radio network design.

Table 2: Example of global parameters for estimating coverage

Environment	Dense Urban	Urban	Sub-Urban	Rural
Surface area	Depends in scenario	Depends on scenario	Depends on scenario	Depends on scenario
BS antenna height	25 m (tbc)	30 m (tbc)	30 m (tbc)	50 m (tbc)
BS configuration	Omni-directional or tri-sector	Omni-directional or tri-sector	Omni-directional or tri-sector	Omni-directional or tri-sector
Indoor margin	Depends on scenario	Depends on scenario	Depends on scenario	Depends on scenario
Cell edge coverage probability	90% (tbc)	90% (tbc)	90% (tbc)	75% (tbc)
Shadowing standard deviation	8 dB (tbc)	7 dB (tbc)	7 dB (tbc)	5 dB (tbc)

3.2.1.2 Radio system parameters

The main common radio system parameters that will influence coverage and capacity are the following. All the parameters (except the channel bandwidth and system load) have a significant impact on the coverage of a site. The channel bandwidth and the system load have an impact on the cell capacity. It is important to note that the proposed values are indicative only since they will be consolidated during future WP4 tasks.

Table 3: Parameters and indicative values for estimating coverage

Parameter	Value (indicative only)	Comment
Frequency	400 MHz and 700 MHz	As per CEPT FM49 options
Channel bandwidth	2x5 MHz and 2x10 MHz	2x10 MHz only at 700 MHz
System load		Impact the capacity
BS output power	2x40 W or 2x60 W	MIMO be default
BS antenna gain	Omni / Directional	Gain depends on frequency band and type
BS architecture	TRU or RRH	Impact on cable losses
Terminal output power	23 dBm or higher (e.g. 31 dBm / 37 dBm)	May depend on band and terminal type. 23 dBm is default LTE value

Terminal type	Handheld / Vehicle	
Terminal antenna gain	0 dBi (handheld) / 2 dBi (vehicle)	
Terminal height	1 m (pedestrian), 2 m (vehicle)	May depend on terminal type
Body loss	10 dB	Only for pedestrian

3.2.1.3 Services and user profiles

Radio network design will also be impacted by the user traffic profiles, the user density.

An important parameter that significantly impacts the coverage is the service guarantee at cell edge in uplink. It is proposed to use a default value of 512 kbps (this allows to transmit a video of operational quality). Other values can be proposed such as 128 kbps (e.g. terminal not transmitting video), 1 Mbps or 2 Mbps.

With that last parameter and the parameters presented before, base station coverage will be evaluated.

To evaluate the capacity to be offered additional parameters are required such as user density and user profiles. The first one is the user density. The user density may be different according to the environment, to the mission (e.g. routine and major event) and to the organisations (police, fire brigade, emergency medical services...).

For the user profiles, two approaches can be followed:

- A simple model may consist in defining the average throughput per user (in downlink and in uplink) during routine and major events. It is to be noted that different type of users could be defined. In that case, the capacity to be offered per environment would simply be the user density multiplied by the average throughput per user,
- A more sophisticated model may detail each user profile with different types of services (e.g. voice, video, and data) with different quality of service during routine and major events. In that case, a statistical approach could be used to evaluate the capacity to be offered so that the system provide service to the users x% of time.

The user profiles needs to be consolidated with inputs from WP2.

3.2.2 LTE network architecture design

Another aspect influencing the cost of deploying and operating a LTE network lies in the architecture of the system. It is proposed to take into account two predominant aspects:

- The architecture of the core network,
- The backhaul network connecting the radio sites to the core network sites as well as the backbone connecting the LTE network to command and control rooms.

3.2.2.1 LTE core network design options

Figure 1 illustrates the proposed different options that can be used to deploy a LTE core network:

- Deployable: an autonomous system that consists of a small LTE core network and a few base stations covering e.g. an incident area (e.g. disaster recovery); alternatively, this system can be connected to the network through e.g. a satellite link,
- Centralized: the conventional way to deploy a core network. In this option, different redundancy model (technical and or geo-redundancy) to provide the required level of availability

- Distributed: an alternative way to deploy where multiple small core networks providing services to 10 (tbc) base stations are deployed in the system; every small core network is interconnected with other small core networks for mobility and resiliency aspects.
- Isolated cell operations: it is foreseen in 3GPP release 13 to have ultra-resilient mode of operations where small units (probably embarking a subset of core network functions) will be deployed to provide services to a few base stations even if the base stations are disconnected from the main core.

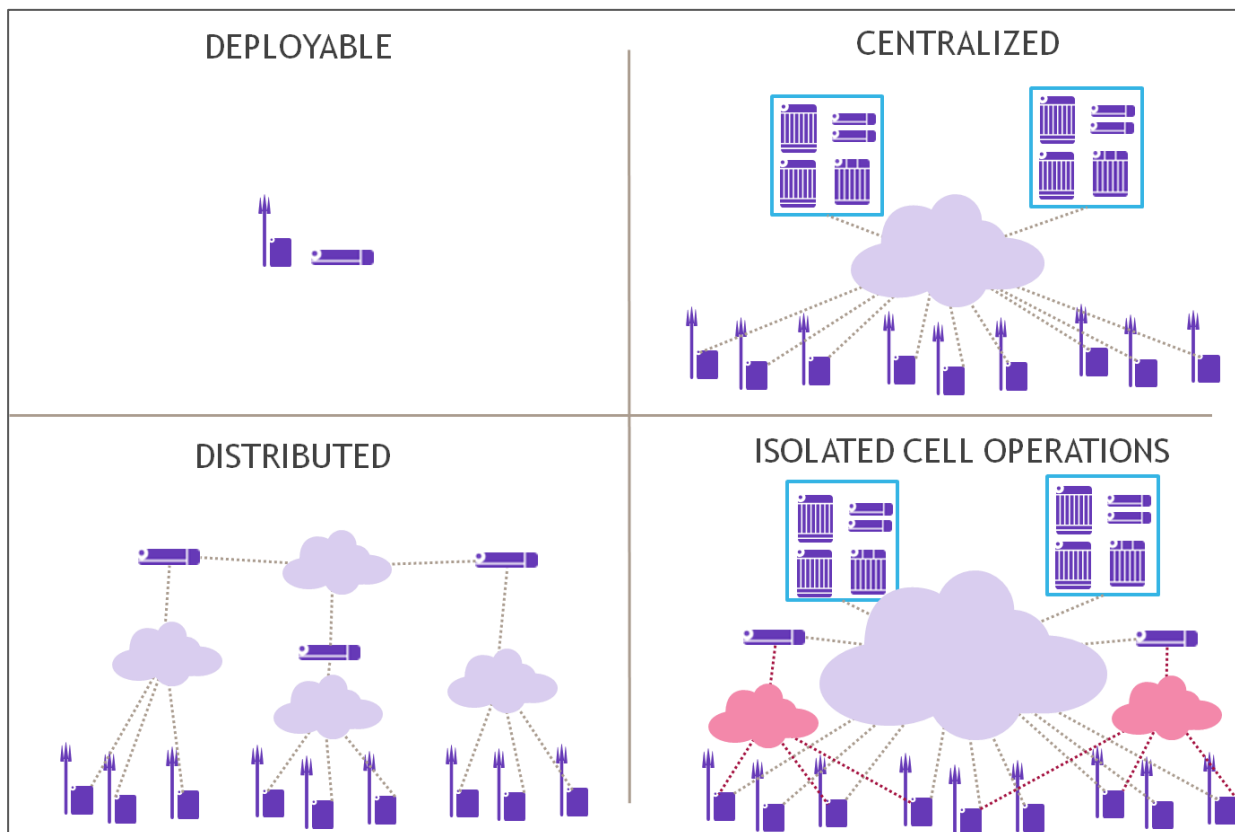


Figure 1 - Possible LTE core network architectures

3.2.2.2 Backhaul and backbone architecture

For the backhaul architecture two main options can be considered:

- Own-built backhaul: in that case, in most situations, the backhaul network will consist of a microwave based portion (to convey the traffic from a cluster of base stations) and a fibre based portion connecting the different microwave clusters to the LTE core network sites. Figure 2 illustrates this option for the centralized and distributed core network model.
- Rented model where each base station is connected to the core network using a carrier provider.

Similarly, Command and Control (C2) rooms will need to be interconnected to the LTE network. This will be done either using the own-built backbone (e.g. fibre and IP/MPLS based) or by leased lines between the EPC sites and the C2 sites.

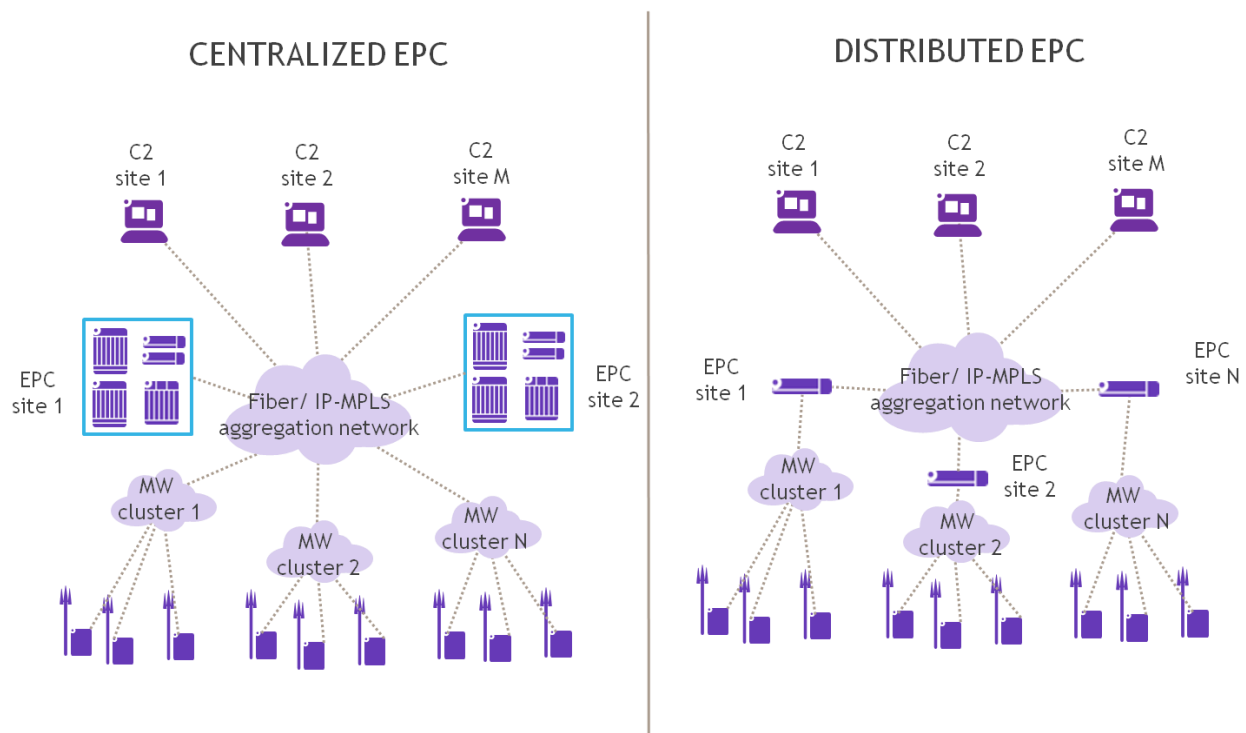


Figure 2 - Own-built backhaul/backbone options

3.3 Impact of Physical Layer Parameters on Wireless Dimensioning

In order to estimate and evaluate the impact of wireless channel phenomena such as path loss, shadow fading and interference and/or noise on the boundaries of reliable reception and therefore the quality of service for PPDR applications, it is imperative to take into consideration the propagation mechanisms as well as the intrinsic channel and topology characteristics and their impact on the transmitted signal.

Since a 2 sq.km city area is considered, it is necessary to estimate the maximum coverage area for given specifications provided by the employed technology of the wireless system in question (carrier frequency, reference path loss at given frequency maximum transmitted power, antennae gains, receiver sensitivity level) and the obstacles that meddle with the signal path.

The aforementioned channel and system variables need to be introduced as either input parameters in the SALUS TE tool for CAPEX and OPEX calculation, or as metrics that will be employed in order to narrow down – and possibly, single-handedly specify – the value range of the input parameters.

A coverage area of 2 sq. km can be approximated with a square surface of 1.5 km per side, leading to a calculated surface of roughly 2.25 sq. km which is an acceptable approximation, as shown in Figure 3. Since in such a scenario the maximum distance between two points within this square 2D area is 2.12 km as shown in Figure 3, we can roughly accept a distance of 2 km as the maximum transmitter-receiver separation within the aforementioned city area. This will be employed in our path loss calculations in order to specify the maximum area that can be covered reliably according to propagation losses and specifications of each wireless system involved in our PPDR scenario (Wi-Fi, LTE).

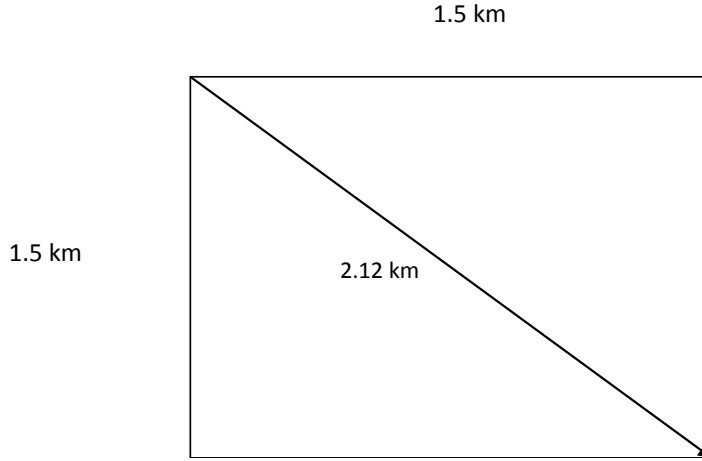


Figure 3 - 2D square area as an approximation of 2 sq. km city area of interest

The minimum distance that can be assumed between transmitter and receiver, is defined by the critical distance for the averaging of small-scale (multipath) phenomena, in order to provide reliable measurements for the path loss estimations [25]. This is roughly equal to $10 \times \text{wavelength}$, which equals 0.5 meters (approximately) for the 2.4 GHz Wi-Fi channel and approximately 5 meters (ten times more) for the 700 MHz spectrum which has been suggested as potential PPDR carrier frequency. Therefore a minimum distance of 5 meters needs to be employed to provide averaging of small-scale phenomena for all potential carrier frequencies within the PPDR case study discussion.

For reasons of mathematical safety, a minimum distance of 10 meters will be employed. This distance also corresponds to a reference path loss $P_{Lo}(dB)$ that will be employed in the path loss and received power level calculations. This reference path loss is calculated directly from the Free Space path loss model, since it is considered to be a relatively obstacle-free area around the (mobile) wireless user (or BS) in question:

$$P_{Lo}(dB) = 32.45 + 20 \log_{10} f(MHz) + 20 \log_{10} d(km) \quad (1)$$

Where: the carrier frequency f is introduced in MHz. According to the SALUS discussion, proposed frequencies for the PPDR application include the 700 MHz channel, the 2 GHz channel and the 2.4 GHz as part of the complementary Wi-Fi system, as well as LTE frequencies.

Already three fundamental parameters have been discussed: the carrier frequency, the transmitter – receiver distance (minimum and maximum value range) and the reference path loss, as employed from the Free Space model (which is a logarithmic expression of the Friis idealistic model). These can be employed to provide calculation of the average path loss due to free-space propagation. Since, however, the residue of free – space propagation out of the overall path loss constitutes the “excess path loss” [26], it is imperative to provide a metric for the large-scale fluctuations of the received power, i.e. a parameter for the variations of the local mean power. In such cases, a zero-mean Gaussian variable is employed, since the typical distribution of the logarithmic values of the local mean power is Gaussian (log-normal shadow fading [27]).

$$P_R(dBm) = EIRP(dBm) - P_{Lo}(dB) - X_\sigma(dB) - 10n \log_{10}(d) \quad (2)$$

The local mean value of the received signal power can be provided by Eq.2, where $EIRP(dBm)$ stands for the effective isotropically radiated power (transmitted power*transmitter antenna

gain) in dBm, $P_{Lo}(dB)$ stands for the reference path loss at a distance of 10 meters, $X_{\sigma}(dB)$ stands for the shadow fading (excess path loss) and $10n\log_{10}(d)$ stands for the free-space propagation losses, where the path loss exponent is assigned a value of $n=2$ in order to incorporate exclusively losses due to propagation in free space.

The shadow fading variable $X_{\sigma}(dB)$ is calculated directly from the shadow deviation $\sigma(dB)$, also known as shadow depth, that is derived from the obstacles of the T-R path and the overall topology in question. Four values will be considered in our subsequent case study: 16 dB that corresponds to a severely shadowed urban scenario, 12 dB that characterizes a shadowed urban scenario (typical values when studying urban cellular deployment), 6 dB which refers to a less severe shadow fading scheme and 0 dB that is employed only for reference value purposes since it corresponds to an obstacle-free topology and is inappropriate for our urban scenario [27]. In an obstacle-dense topology, log-normal shadow fading is typically considered, expressed, in terms of average path loss and respective average received signal power, by the log-distance model. Since however, noise and interference from other operating systems, either in the 700 MHz from “traditional” broadcast systems, or in the 2.4 GHz from other operating Wi-Fi networks, might be a critical problem, this is another metric that needs to be studied. The average SNR in such a case is provided by:

$$\bar{\gamma}(dB) = EIRP(dBm) - P_{Lo}(dB) - X_{\sigma}(dB) - 10n\log_{10}(d_M) - N(dBm) \quad (3)$$

Example for the 2.4 GHz channel

Considering a total effective isotropic radiated power of 17 dBm (50 mW), an average noise level of -85 dBm (in concurrence with measurements conducted in outdoor 2.4 GHz scenarios), a reference path loss of 40 dB (for 2.4 GHz), a path loss exponent of $n=2$ in accordance with free space outdoor propagation, as all other attenuation losses are expressed via the shadow fading variable X_{σ} , which is a zero-mean Gaussian variable (in dB) with 95% coverage probability, Figure 4 - Local mean SNR versus distance and shadow fading is derived, for the aforementioned shadow fading scenarios.

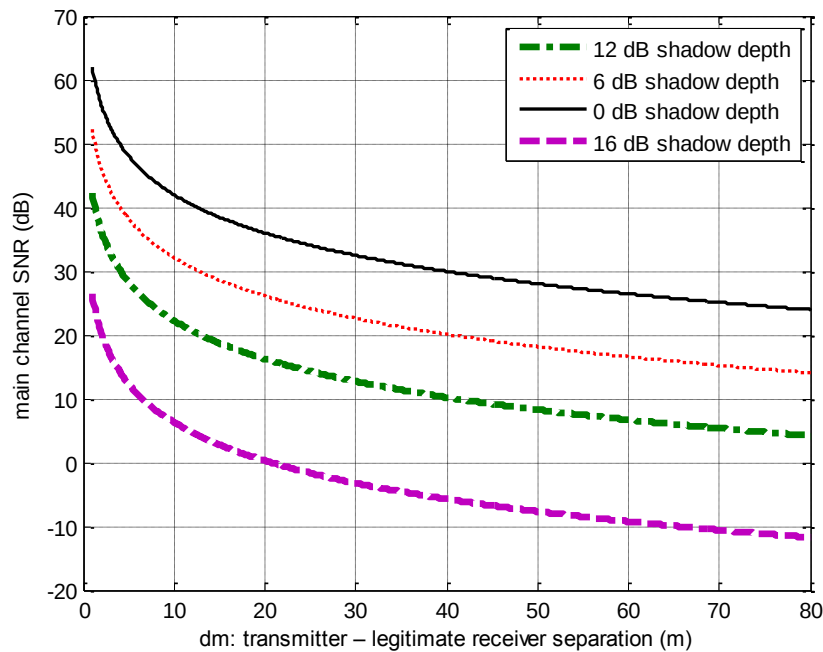


Figure 4 - Local mean SNR versus distance and shadow fading

3.4 OPEX Parameters

Operational expenditures (OPEX) represent a significant cost for PPDR organisations. Defining a model for OPEX is a complex task since it reflects costs that may not be easily publicly accessible and that may vary from an organisation to another one. For SALUS TE tool, it is proposed to model OPEX as the sum of two main items:

- Subscription fee for mobile broadband PPDR users (when relying on the services from a mobile service provider),
- Network OPEX, representing all the costs to operate and maintain a privately owned network.

3.4.1 Subscription fees

In future mode of operations, PPDR organisations may rely on one or several mobile service providers to have access to broadband services. According to the various deployment models for the broadband PPDR services depicted in §3.1, the subscription fees might be different. For example, a PPDR organisation relying only on MNO(s) to have access to all broadband services may pay a premium since the MNO(s) would have to provide differentiated services to the PPDR users. The following table describes an OPEX model for the subscription fees for the different deployment models.

Table 4: Subscription fee models

Deployment Model	Number of PPDR users	Fees	Comments
MNO	100% of broadband PPDR users	Monthly or annual fee (depends on volume and SLA) per MNO (1 to typically 3)	Fees are likely to be higher than a standard user to ensure required availability and priority levels.
MVNO	100% of PPDR users	Bulk volume per month or per year per MNO	Fees are likely to be lower than the MNO case (bulk volume vs. per user fees)
Dedicated network	% of PPDR users that may access MNO	Monthly or annual fee per PPDR subscriber per MNO	Fees are likely to be lower than a standard MNO subscriber since they would be used only for non-mission critical services.

3.4.2 Network OPEX

According to public studies, yearly OPEX of mobile network operators represents around 1.5 to 2.5 times the initial expenditures [22]. A larger portion of MNO OPEX is dedicated to marketing, customer care and mobile subsidies that are not costs relevant for PPDR operators. However, network OPEX represents around 25% of MNO OPEX according to a study done of European MNOs [23]. This includes personal costs, maintenance and upgrade of network elements, site rentals, energy and backhaul lease line costs. In another study, a typical split of network OPEX is proposed [24], see Table 5.

Based on this information, it is possible to define a simple model of network OPEX according to the different models of deployment for the LTE network based on OPEX to CAPEX ratio and on the split of network OPEX items (Table 6). In that case, the network OPEX is expressed as:

$$\text{Network OPEX} = \text{OPEX to CAPEX Ratio} \times \text{Network OPEX \%}$$

Table 5: Network OPEX typical split [23]

OPEX Model	Product & Platform Dev	NW Capacity - Facility	NW Capacity Equipment	O&M Service Delivery	O&M Service Assurance	Maintenance	MBH/LL	Leases & Rental	Support & Energy	TOTAL
Service Platform	0,9%		0,2%	0,4%	1,4%	3,0%			1,0%	6,9%
RAN	0,8%		1,7%	1,5%	5,1%	6,0%			5,0%	20,1%
Core	0,1%		0,1%	0,8%	1,7%	2,2%			1,0%	5,9%
New Transmission	0,7%		1,1%	0,4%	3,8%	1,8%			1,0%	8,9%
Legacy Transmission	0,1%		0,7%	0,4%	2,5%	1,9%			1,0%	6,6%
Site Facilities	0,2%	2,5%	0,5%	0,3%	0,4%			30,0%	2,6%	36,6%
Other							15,0%			15,0%
TOTAL	2,9%	2,5%	4,4%	3,8%	15,0%	14,9%	15,0%	30,0%	11,6%	100%

Table 6: Simplified Network OPEX model

Deployment Model	OPEX to CAPEX ratio	Network OPEX %	Comment
MNO	2 (range = 1.5 to 2.5)	0	No network OPEX for LTE network in that case
MVNO	2 (range = 1.5 to 2.5)	~ 25% of Core Network and Services Platform CAPEX	Around 13% of E2E network OPEX
Dedicated network	2 (range = 1.5 to 2.5)	25% of Network CAPEX	

3.5 Interworking with TETRA

Due to their intrinsic security, there is no COTS solution allowing to interconnect legacy PPDR networks to external networks. Nonetheless, the architecture would provide an IP based gateway from existing TETRA core systems. The interface would be basically a 'fixed IP client' interface, as today already exists as proprietary solutions in TETRA core implementations for control room clients. The interface should be optimised to provide required scalability (number of supported 4G terminals), the required performance (PTT set-up times, voice delay), required PMR security as well as implementability in 4G mobile terminals.

Different protocol alternatives: TETRA Layer3 PDU...XML....SIP..(DCOM) will be studied and most feasible to be selected for an architecture definition and definition of a demonstrator. Interface criteria include both TETRA core architecture preferences as well as mobile terminal architecture and operative implementation preferences.

The selected interface alternative and its provided functionality must fill the operative requirements of end-users, the terminal use concept and describe the co-use of existing TETRA terminals. The IP access like 4G LTE must be an independent entity to provide the IP bit pipe for the TETRA services: authentication, group/PTT signalling, coded voice transport. The default 4G LTE terminal should be a standard cellular LTE terminal with optionally several SIM slots, also to include security module (smartcard).

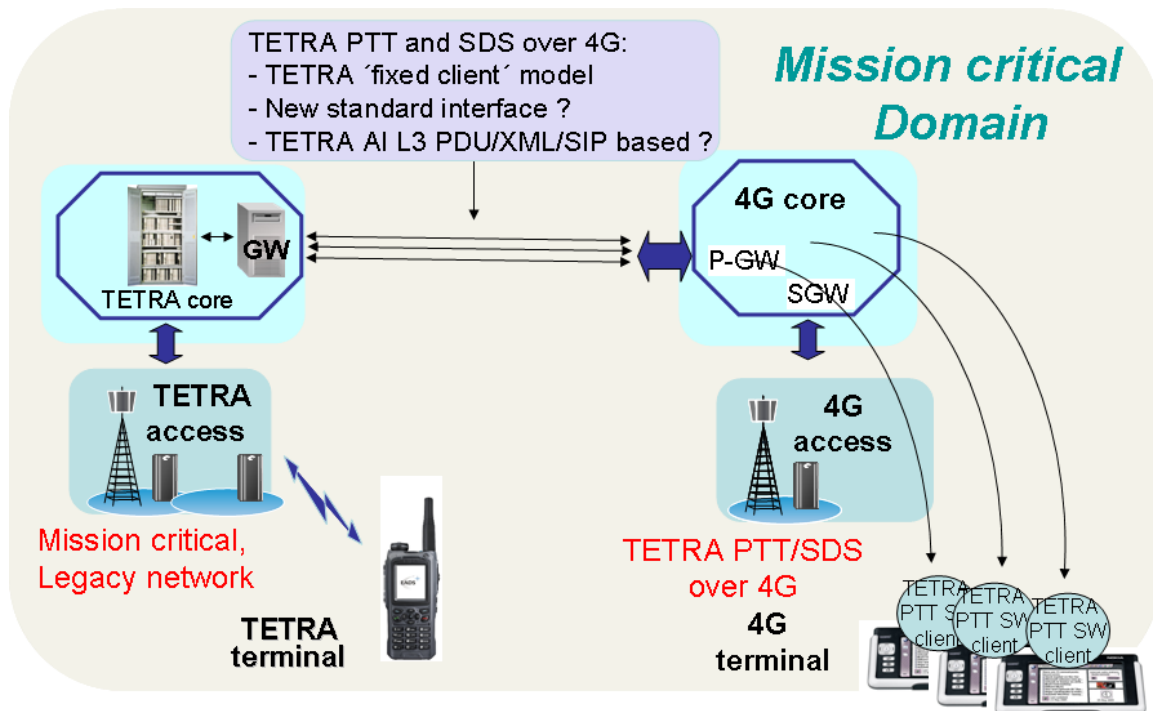


Figure 5 - The high level architecture of the IP interface using 4G access as example

3.6 CAPEX parameters

Assumptions:

Network Build Model:

- A pragmatic approach that achieves high quality wireless broadband service using spectrum dedicated for public safety—the 5+5 MHz public safety broadband spectrum—to provide public safety with a dedicated Radio Access Network (RAN).
- Assumes that public safety agencies on an area-by-area basis will collectively issue a Request for Proposal (RFP) for that area for the building out of the public safety broadband network.

Funding is based on an asynchronous build where existing operators' infrastructure would be expanded to include the "lighting" of the public safety 700 MHz broadband spectrum to give public safety a dedicated RAN.

- Assumes LTE commercial rollout availability to 95% of the population will be achieved by market forces by 2015.
- For the 95% that are likely to be served by LTE-based operator plans, this would be an asynchronous expansion by an operator who has built out an LTE network.
- For highly rural area, where there is not market commitment for an LTE network, build out was modelled to use 2G infrastructure plus new towers where necessary.

Subscriber device model:

- Commercial power levels (23 dBm) for handheld devices, except in highly-rural areas. Public safety agencies can choose to equip their officers with slightly larger handheld devices with small external antennas and larger batteries, thus gaining 2 to 3 decibels (dBs) of additional power. These devices will provide public safety officers with superior coverage and high speed near cell edges.
- In highly rural areas the subscriber device supported by the network is a vehicular device using an externally mounted antenna (EMA). Commercial handheld devices will

also work in these areas for much of the area within a cell site, but at reduced speeds as one gets closer to the cell edge.

- The model contains no device funding for handheld or the vehicular device with the EMA, as that was assumed to be the responsibility of each individual agency.
- The subscriber devices should be substantially lower in costs than they are today for public safety because of the ability to leverage the commercial device ecosystems. In the operating system, the baseband chipset and the RF chipset are the components of the device that require high volumes to drive costs down. These components will also be used in commercial deployments and thus will be in high volume.

Network services:

- Data and video services via IP Transport in early years offering a more reliable, high performance, and more cost-effective version of the commercial wireless aircard services that some public safety officers purchase today.
- Commercial voice via VoIP over LTE in the medium term as that becomes available on LTE networks.
- Interoperable, mission-critical voice, data and video IP networks and applications as the long-term target.

CAPEX FOR PUBLIC SAFETY 700MHz BUILDS	
Urban Cost per cell Site for Upgrade	117000€
Urban Cost per cell Site for New Site	161000€
SubUrban Cost per cell site for Upgrade	165500€
SubUrban Cost per cell site for New Site	206000€
Rural Cost per cell site for Upgrade	176500€
Rural Cost per cell site for New Site	282000€
% of Sites Upgraded	20%
% of Sites New Build	80%

4 SURVEILLANCE SYSTEMS

4.1 Video surveillance systems

Video surveillance systems are used to monitor specific areas. The cameras are connected to a recording device or a network and images are observed by security guards or public safety officers. Analysis of video images is nowadays done by automated software. The amount of footage is also drastically reduced by motion sensors which only record when motion is detected.

Surveillance systems have developed in three generations [15]. The first generation systems used analogue equipment throughout the complete system. The second generation systems use digital back-end components, which enables automated analysis of incoming images. The third generation systems are fully digital. They are able to handle a large number of cameras, and support large geographical spread areas with many monitoring points. From the image processing view, they distribute processing and storage capacity over the network in order to achieve scalability and robustness. Currently some vendors offer scalable platforms with up to 10,000 cameras in a single operations manager and more than a million cameras in a federated system [12].

An important development in third generation systems is the use of IP networks. IP technology eases the provision of scalability in terms of sites, cameras, viewers, and storage. Prior to IP Surveillance solutions, organizations relied on surveillance systems with its separate infrastructure. However, there are significant advantages associated with IP Surveillance versus video surveillance with dedicated infrastructure. First of all, there is only one network to manage. The total cost of ownership is lower especially where new installations are being considered since not having to install a dedicated network cabling infrastructure in addition to the data network avoids an added CAPEX investment. In addition, it is easy to move locations and expand the system. Security is enhanced.

An additional advantage is that with IP technology, recording devices do not require direct connection to cameras, enabling cameras to be placed at any point within or outside the facility that is connected to the network. Network video recorders, virtual matrix software and viewers can be located where they can best be serviced and used, not just at the end of a camera's coax cable.

Wireless technologies play a very important role in contemporary surveillance systems. Wireless video solutions are generally easier and less expensive to plan and to deploy than wired solutions. A typical wireless system can be deployed or extended in few days, in contrast to an in-ground fiber or cable network.

Figure 6 shows the architecture of an end-to-end networked wireless video surveillance system. The back office integrates the various systems, gathers information from different sources, and runs the application software providing analytics, management and sharing capabilities. The network provides transport, distribution, and access of the video via wire line and wireless transport. The edge devices may comprise a variety of both fixed and mobile cameras, including in-vehicle video platforms, handheld devices and wearable cameras and sensors.

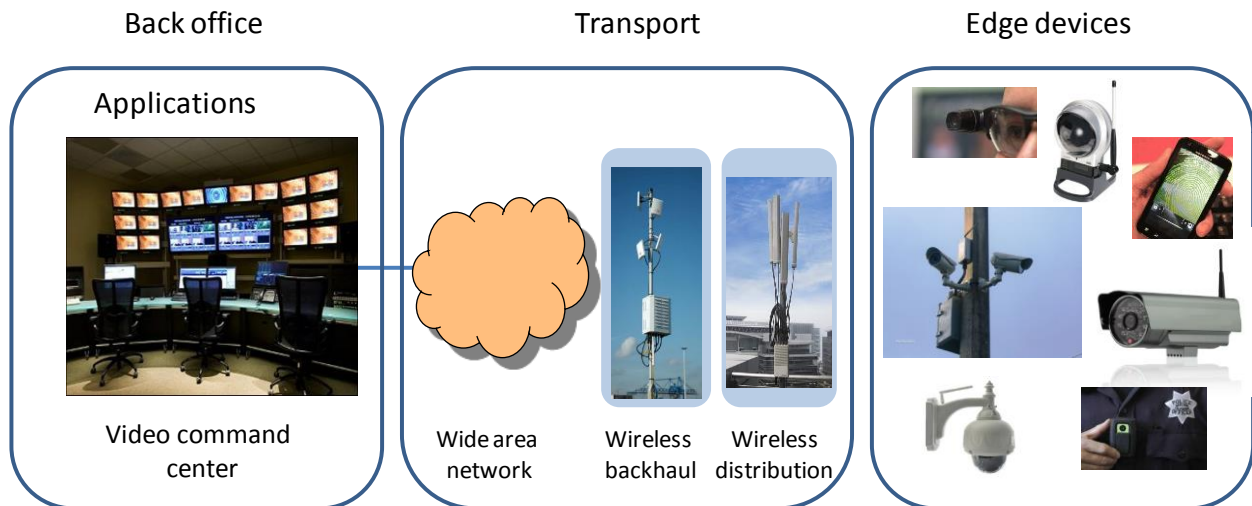


Figure 6 - Architectural components of wider area wireless video surveillance system

Networked video surveillance systems may involve a large number of cameras from very heterogeneous sources. For instance, the city of Chicago operates a networked surveillance system which combines government's video feeds with feeds of the private sector, with the cameras installed in city buses, businesses, public schools, subway stations, and so on. Even home owners can contribute, and so the city incorporates the video feeds of a total of 15,000 cameras.

4.2 Components of a video surveillance system

The typical components of a (wireless) video surveillance system include edge devices, network equipment, and software applications.

4.2.1 Edge devices

Surveillance cameras are the traditional edge devices of surveillance systems. Pan-tilt-zoom (PTZ) camera are often used for surveillance. PTZ cameras have features for remote directional and zoom control. They may have a built-in firmware program that allows to follow moving objects, as well as to estimate their size and distance from the camera. Wireless cameras are also wide spread. For example, AXIS [11] offers IP cameras that support of IEEE802.11 b/g/n and are tamper resistant with intelligence to detect and notify when tampering occurs.

In addition to high-end cameras, there are a diversity of CE cameras than can also be integrated to the surveillance system, as wearable cameras, cameras of hand held devices, etc. Modern surveillance systems are becoming multisensory platforms. Besides cameras, other sensors are used to detect anomalous events. Microphone arrays are used for audio surveillance, complemented with sound analysis software.

4.2.2 Network

The network is an essential component of a surveillance system. The size and functionality of the network depends on the coverage area of the system and location of the command and control centre. Local networked systems are connected to a local area network, while large system make use of access and distribution networks that connect the edge systems to a high-speed optical fiber-based transport network. The access network may comprise a back haul for further broadband transport, and finally a local area network for the local distribution and access. Different wireless and wired technologies as well as combinations of them are used in the access network.

As mentioned before, IP technology plays an important role in contemporary networked video surveillance because it does not require a dedicated infrastructure, lowering significantly the

installation and maintenance costs. Its large flexibility makes modification and expansions of the systems easier.

4.3 Video coding

Video compression techniques are used to reduce storage and bandwidth requirements. The most commonly used format for recording, compression and distribution of video content is the H.264/MPEG-4 Part 10 or AVC (Advanced Video Coding) [14]. Although H.264 is typically a lossy compression, it is possible to create lossless encodings with H.264.

The H.264 video format has a very broad application range that covers all forms of digital compressed video from low bit-rate Internet streaming applications to HDTV broadcast and Digital Cinema applications with nearly lossless coding. The CCTV (Closed Circuit TV) and Video Surveillance markets have included the technology in many products.

4.4 Video content analysis (video analytics)

Modern high-definition cameras computer-controlled technologies to identify, trace, and categorize objects. Video Content Analysis (VCA) is the capability of automatically analysing video to capture and define temporal events that are not based on a single image.

VCA systems are able to recognize changes in the environment, identify and compare objects stored in a database by size, speed, and even colour. VCA analytics can be used to detect various unusual patterns in a videos environment such as anomalies in a crowd. Another feature of VCA is that it can track people on a map by calculating their position from the images. Facial recognition may be also possible.

4.5 Wireless video surveillance

Wireless technology plays an important role in contemporary video surveillance systems. Wireless cameras can be placed in areas where trenching or cabling for internet may be impractical or expensive.

For the backhaul, video surveillance used to be deployed primarily using the existing wired facilities. However, long range wireless technologies are introducing new capabilities that significantly extend the reach of existing networks. OFDM coupled with advanced antenna technologies as beamforming and MIMO have enabled significant performance improvement in radio communication. This makes wireless broadband highly attractive as a building block for high capacity video surveillance networks. The use of a high speed wireless link may be a good alternative to paying a telecom operator for a dedicated link.

A large majority of wireless products use IEEE802.11a/b/n/ac technology and mostly operate in license-free bands. Many products use some quality of service (QoS) features based on IEEE802.11e standard, as the Wireless Multimedia Extensions (WME). WME prioritizes traffic according to four Access Categories (AC) although it does not provide guaranteed throughput. Adaptive antenna technology is used to maximize range, reliability and capacity. Vendors such as Rukus [16] wireless, Motorola [13] Aruba Networks Wavesight [19] and Alvarion [10] are providing these type of products. Some offer surveillance products with “transmission rates up to 600 Mbps.

Most of those vendors also offer IEEE802.11 products with meshing capabilities [18]. Meshing is used to bridge long distances, by splitting the total distance into a number of shorter hops. Different channels for incoming and outgoing links should be used for allowing simultaneous transmissions on orthogonal channels. Some systems are self-organizing, self-healing and self-optimizing, being able to automatically adjust to the topology changes in the network. This in general results is less equipment and therefore reduced CAPEX. An example of a wireless

surveillance system using long distance links, meshing, and wireless cameras based on IEEE802.11 is shown in Figure 7 - Wireless surveillance system.

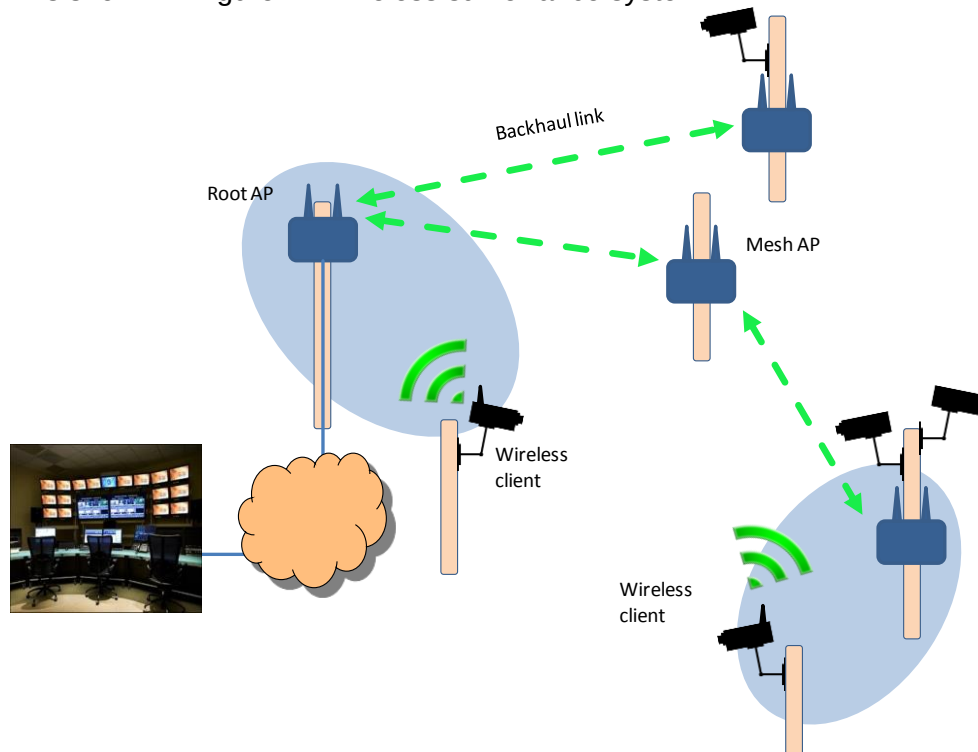


Figure 7 - Wireless surveillance system

For mobility support, products with 3/4G interfaces are used. Some products use link aggregation to provide larger data rates. An example is ThirdEye of Mushroom networks [17], which accomplishes bonding both in uplink and downlink directions, so that the video feed from the PTZ camera can have higher throughput and higher reliability.

4.6 Issues for CAPEX for video surveillance in public places for public safety

The following issues impact the CAPEX of a surveillance system:

- **Coverage area.** It will determine the number of cameras and their location. It may include support for full vehicular mobility.
- **Support for mobile surveillance.** Fixed solutions keep those in the command centre informed. However, the ability to stream video from the command centre to a mobile unit or an officer in the street may be of significant help for on-scene professionals.
- **Type of cameras.** The resolution depends on the primary goals. In case of deterrence, the mere presence of a camera is enough; it is not necessary to spend vast sums on the latest technology. If the aim is to collect evidence for prosecution and conviction, then high resolution equipment is necessary. Another issue is the size of the area the camera has to view. Effectively monitoring large areas requires cameras that can pan, tilt and zoom (PTZ camera) to provide a more detailed view. Another consideration has to do with whether the system will be used at night because this requires infrared cameras or further illumination by an infrared light source. Location of the camera is another important issue.
- **Entity that will operate the system.** For reasons of funding, partnerships with of the police with local authorities and civilian organization may be chosen. In such a case, a

direct communication link should be arranged from the local surveillance control room, to the police.

- **Video quality.** The quality of the video depends on parameters such as frame rate, colour depth, resolution and video format. Regarding frame rate, live video feeds require a minimum rate of 10-15 frame per second. Colour depth can range from black and white, grayscale or true colour. Resolution is typically measured in the number of pixels with each picture frame. Obviously higher resolution, higher frame rates and video with colour will contain larger data than lower resolution black and white images, requiring more communication and storage capacity. The video format or compression algorithm, as MPEG 4 and H.264 has to be carefully chosen according to the particular situation.
- **Network.** One of the issues is the choice between wireless and wired or a combination of both. This depends on the actual topology and geographical dispersion. The speed of deployment and ease of expansion are also very important issues. Whether there is already an existing (analog) system or not also plays an important role.
- **Storage.** This is one of the most cost intensive components of the overall system. In addition to the video characteristics, the choice depends on issues, such as purpose of the video (monitoring or collection of evidence), the period the data has to be kept, and the number of cameras and video feeds.
- **Video analysis software.** Proper analytic software decreases human error, and increases the efficiency of the staff.
- **Other issues.** Up and down link bandwidth, security and access control, back up requirements, provisions for cost-efficient network expansion.

5 TECHNOECONOMIC TOOL

Demands for new PPDR applications and services, are leading towards the creation of new services and applications, which use innovative network infrastructures based on LTE, TETRA/TETRAPOL and Ad-Hoc Wireless Networks. The aim of such scenarios is the design of novel infrastructure and the creation of new PPDR applications, in order to increase the service acceptance and penetration to the market and eventually the potential profit for the PPDR organizations.

In order to accurately estimate and assess the investments that are required, the CAPEX and OPEX indexes are employed as presented in Figure 8.

Concurrently the Total Cost of Ownership (TCO), the Break Even point (BEP) and the risk assessment can further improve the accuracy of our estimations.

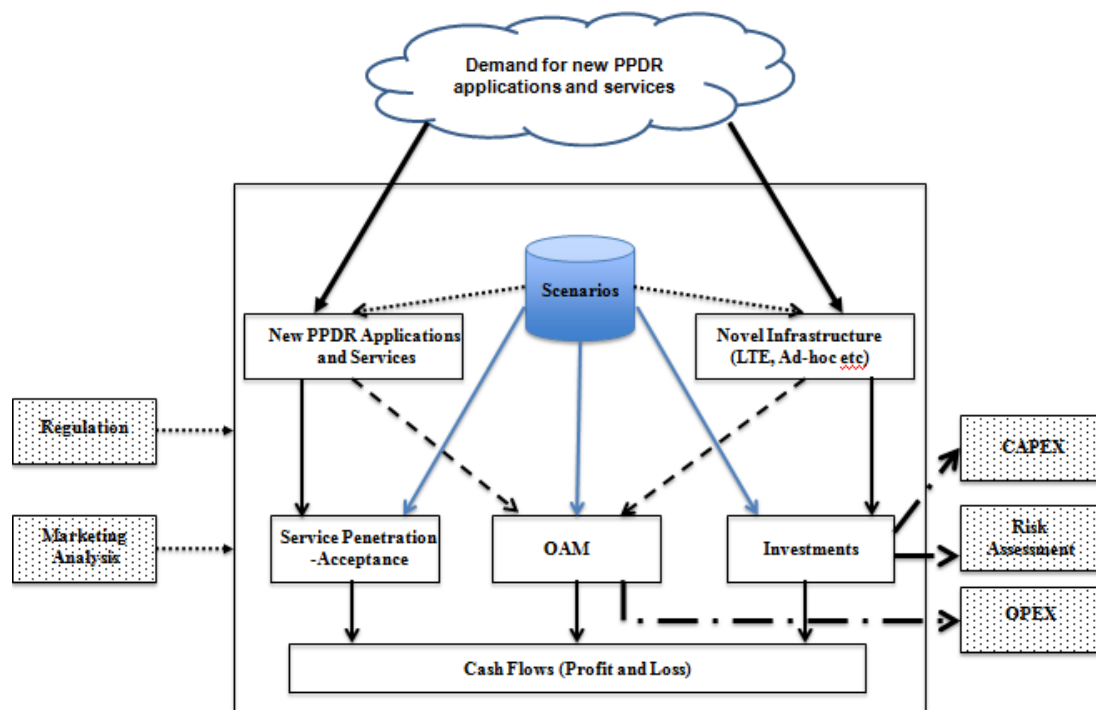


Figure 8 - The incentive behind the need for the SALUS techno-economic tool

5.1 General Description

The Operating Expenditures (OPEX) is a metric used to express the expenses required to operate a system or product [1]. The Capital Expenditures (CAPEX) is the corresponding metric used to quantify the expenses to acquire or upgrade physical assets that will create future benefits and their lifetime extends beyond the taxable year [2]. While the CAPEX index is (in the case of the SALUS TE tool) a one-time calculated value, the OPEX is provided for certain time duration in order to provide a deeper understanding of the fluctuation of the operational expenses of certain PPDR networks in terms of time.

The SALUS TE tool aims to provide a calculation of the CAPEX and OPEX indexes in order to efficiently estimate whether the deployment of certain particular technologies of next generation PPDR communication networks and their implementation (based on a specific market analysis) is efficient and profitable for the several organizations. The importance of the SALUS TE tool is

related to the provided services by the PPDR network. The quality and the range of the services depend on the initial investment as well as on the running expenses, the upgrades and the maintenance costs. In general, the reduction of the OPEX favours the involved parties, but after a certain point it can decrease the quality of the provided services. The SALUS TE tool considers a multitude of suppliers and PPDR organizations across Europe and its deployment can assist the decision on which roadmap to follow towards future evolution of PPDR networks.

Lastly, the TCO is crucial for the deployment of any network and the integration of possible new technologies. However, the network operators used to consider the OPEX as an index that does not significantly contribute to the calculation of TCO [7]. This assumption is not justified and OPEX, although more complex to calculate, contribute an important part of the total cost of a network operator [20]. The SALUS TE tool provides this calculated value, based on the provided input.

Figure 9 presents the flowchart of the described SALUS TE tool.

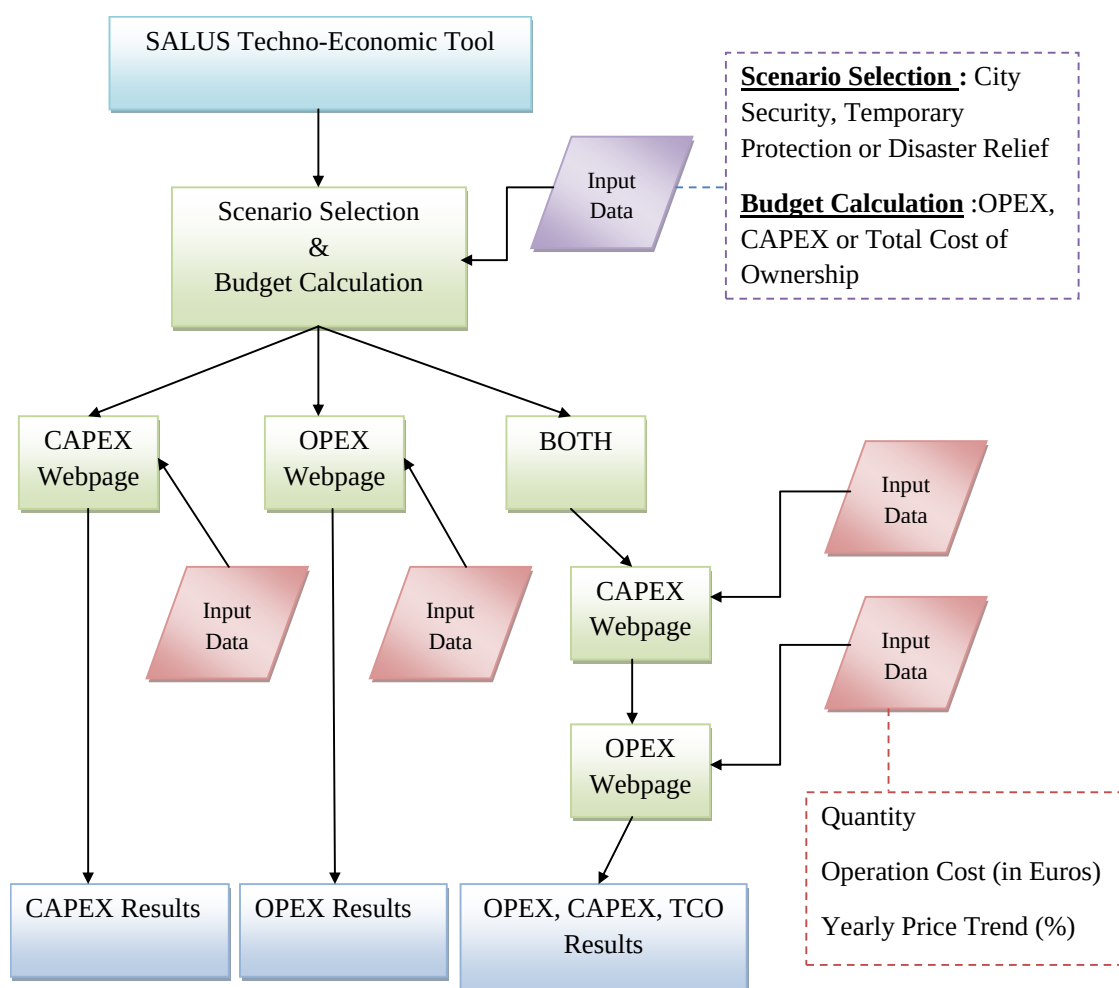


Figure 9 - SALUS TE tool flowchart

5.2 Characteristics

For the successful deployment of a PPDR system, there are some initial expenses that the operators incur and are expressed by the CAPEX index. The SALUS TE tool divides all the required components into the following main categories:

- Base stations
- Network devices

- Spectrum licences acquired
- Site acquisition and development costs
- Premises equipment
- Core network equipment
- Wireless (LTE, Wi-Fi, TETRA/TETRAPOL) backhaul equipment
- SALUS developed entities (interworking gateway, client side application)
- Installation costs

Similarly, the OPEX comprises:

- The network operation, upgrade and maintenance costs (OAM) [8], [9],
- The premises lease costs and utilities,
- The services provisioning and management [3], [4].

The SALUS Techno-Economic tool is implemented based on two mathematic equations [5], where the OPEX and CAPEX indexes are calculated as the summation of:

- All the assets/equipment involved in a particular PPDR system,
- Their amounts,
- The number of newly added equipment that were purchased in each year,
- Their yearly price trends,
- The yearly investment for each asset,
- The yearly operating cost for each asset.

The CAPEX is given by (4):

$$CAPEX^{(i)} = \sum_j M_j^{(i)} c_j^{CAPEX} (1 + P_j^{CAPEX})^{i-1} \quad (4)$$

And the OPEX is given by (5):

$$OPEX^{(i)} = \sum_j N_j^{(i)} c_j^{OPEX} (1 + P_j^{OPEX})^{i-1} \quad (5)$$

Where,

Index i refers to the year examined

Index j refers to the component examined (e.g. spectrum license)

M_j : It refers to the number of component j purchased in year i

c_j : In the case of CAPEX, it refers to the per unit investment. In the case of OPEX, it refers to the operational expenses

P_j : It refers to yearly price trends (e.g. depreciation cost, increase for a rent for a site etc.) for both CAPEX and OPEX

N_j : it refers to the number of the component j

The PPDR operators and organizations might also be interested in the Total Cost of Ownership (TCO) [4], [6] which includes the initial investments/expenses and the running/operating costs. It is provided by the SALUS TE tool based on the equation (7):

$$TCO = CAPEX + OPEX \quad (7)$$

The SALUS TE tool user can compare the CAPEX and OPEX indices as parts of the TCO in the long run and observe how their percentages are modified.

5.3 Implementation

The SALUS TE Tool is implemented in two different but operationally equivalent versions. The first version is a front/back-end web based application. The front-end is based on dynamic web pages that provide a Graphical User Interface (GUI) to collect the data for developing the PPDR network. This data is fed to the back-end, which proceeds to the calculations of the required OPEX and CAPEX indexes. The results are returned to the front-end and presented to the user. This version is intended to be used online for user flexibility and for security purposes. The SALUS TE tool internal operation is also shown in the second version, implemented in Octave tool. It consists of a data-collection file, where the user enters the required data. This file is fed as input to the main calculation program which calculates the OPEX and CAPEX indices and exports the values to the users. No GUI is provided.

5.3.1 General Description of the Application

The user access the SALUS TE tool through the SALUS Website (<http://www.sec-salus.eu/techno-economic-tool/>), using a plain Web Browser. Specifically, this version includes an initial page where the user declares the preferred Use Case/Scenario to examine as shown in Figure 10:

- City Security,
- Temporary Protection,
- Disaster Relief.



Security and interoperability in next generation PPDR communication infrastructures



Techno - Economic Tool

Please select the Scenario that you are interested in:

City Security ▼

Budget Calculation

OPEX ▼

Select an option

CAPEX

OPEX

BOTH

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Figure 10 - Start-up page for the web-based TE tool

The user also selects the analysis to be performed, where there are three options:

- CAPEX, where only the CAPEX index is calculated,
- OPEX, where only the OPEX index is calculated,

- Both indexes, where both the CAPEX and OPEX are calculated sequentially. The TCO index is also provided.

The SALUS TE tool user should consider the desired analysis based on the number of years that this is required. By selecting the *CAPEX* option, the SALUS TE tool provides the input page for the data related to the capital expenditures of the deployed network. If the user chooses only the *OPEX* index, the SALUS TE tool requires the number of years to provide the operational expenses. Finally the option *BOTH* calculates indexes, starting with the CAPEX and then proceeding to the OPEX, so that the TCO can be subsequently calculated. Once the user makes the appropriate selection, the next steps require the input of the main data, as presented in Figure 11.



Security and interoperability in next generation PPDR communication infrastructures



Techno - Economic Tool

OPEX - 1st Year

	Quantity	Operation Cost(Euros)	Yearly Price Trend(%)
TETRA/Tetrapol BS	2	270000	-0.05
TETRA/Tetrapol Gateways	2	200000	-0.05
TETRA/Tetrapol Devices	16	3000	-0.05
Cameras	102	55	-0.05
Control Rooms	3	5000	0.04
Mobile Command Room	1	3000	-0.05
LTE Base Stations	10	5500	-0.02
LTE Gateways	1	2000	-0.02
Spectrum License at 700 MHz	1	200000	0.02
Extra LTE 10 MHz	1	50000	0.02
LTE/WiFi Units	500	450	-0.15
Wi-Fi Base Stations	200	3000	-0.05
(Wireless) Body Area Networks	16	500	-0.05
SALUS Gateway	1	2000	-0.05

Next

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Figure 11 - TE tool data input page, where users provide the required input

The required data consists of:

- The quantities of the scenario components,
- The Investment Cost (in Euros), which only applies to the CAPEX index,

- The Operating Cost (in Euros), which only applies to the OPEX index. This parameter refers to the operation and maintenance costs, rents etc.
- The yearly price trend of each of the component,
- The calculation duration (in Years), which only applies to the CAPEX index.

The data provided by the user is the input used by the back-end of the tool. Once the back-end receives the data provided, it performs the calculations of the OPEX and CAPEX indices and the calculated values are returned to the user. The OPEX value can extend to a time period of user-defined number of years. The TCO index is also provided to further assist the plan of the development of such networks by the PPDR organizations, by expressing the total cost of the system, as presented in Figure 12.



Figure 12 - The OPEX and CAPEX indices as calculated by the SALUS TE tool for a time period of 2 years

In Figure 13, some minor input validation capabilities, provided by the SALUS TE tool, are presented.

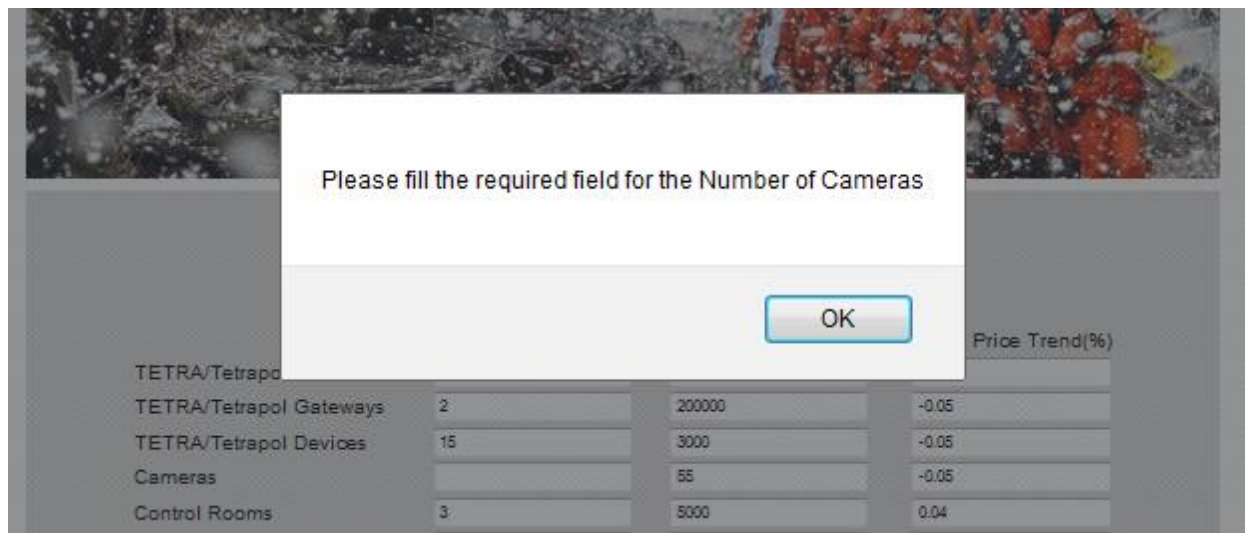


Figure 13 - Input Data validation by the SALUS TE tool

Similarly, the stand-alone version of the SALUS TE tool is presented in Figure 14.

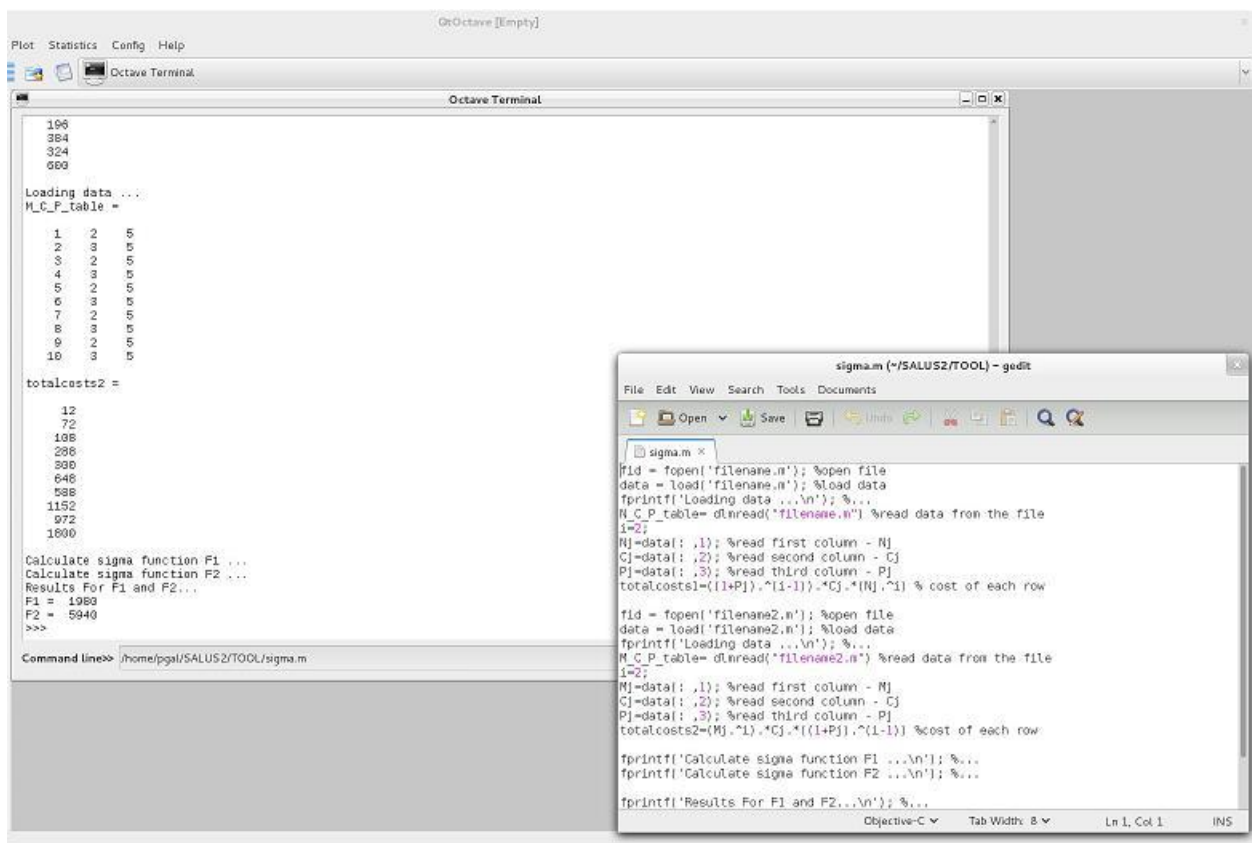


Figure 14- The Octave platform that implements the second version of the SALUS TE Tool

5.3.2 Dependencies

The SALUS TE tool implements a dependency control between the components involved in the calculation of the CAPEX, OPEX and TCO indexes. In particular, the design of a next generation PPDR networks employs a multitude of networking devices, users and spectrum to provide a certain quality of service. Depending on the scenario examined, there are certain dependencies between those components, expressed mainly in the quantity required. Hence, an increase in the number of deployed surveillance cameras is considered to add extra

demands on the required available bandwidth. The SALUS TE tool identifies several of these dependencies and warns the user when the quantities entered as inputs, exceeds the pre-defined limits or do not meet the required metrics.

Figure 15 shows the case where a user drastically increases the amount of desired surveillance cameras, without equally providing enough Wi-Fi Base Stations to meet the increased bandwidth requirements.

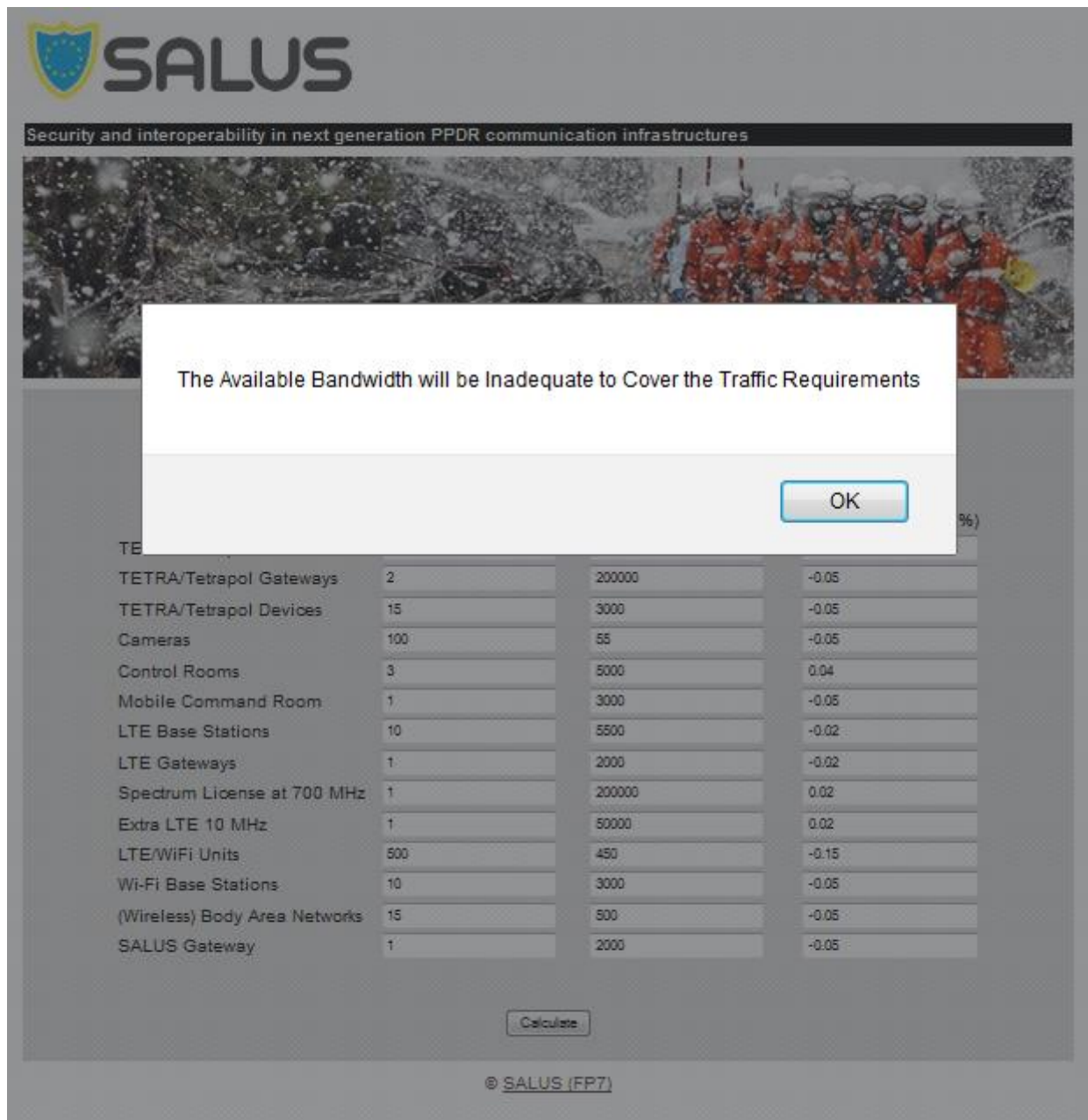


Figure 15 - The SALUS TE tool identifies an inconsistency between the required values of surveillance cameras and the available Wi-Fi Base Stations

6 CONSIDERATIONS AND NEXT STEPS

The SALUS TE tool is a first step in providing a complete techno-economic analysis of the PPDR migration paths. In the scope of T4.2, the techno-economic analysis will be enhanced in order to take into account the regulation aspects from the deployment of new networking technologies for PPDR and the risk assessment derived from each migrated scenario considering “Countermeasure” or “control” of managing risk (e.g. policies, procedures, guidelines, practices and organizational structures that can be administrative, technical, management or legal nature). Total Cost of Ownership (TCO) will be evaluated, and not only the acquisition cost as usually done for legacy networks: this innovative approach is a direct benefit of the past 20 years’ experience of European digital PMR networks roll-out.

The next step on this evaluation is, therefore, to include additional parameters and improve the reasoning of the SALUS TE tool.

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ACRONYMS

CAPEX	Capital Expenditure
GUI	Graphical User Interface
LTE	Long Term Evolution
OPEX	Operational Expenditure
PPDR	Public Protection and Disaster Relief
TETRA	TErrestrial Trunked RAdio
TCO	Total Cost of Ownership
VANET	Vehicular Ad-hoc NETwork
Wi-Fi	IEEE 802.11
WiMAX	Worldwide Interoperability for Microwave Access