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Evolution of Public Safety and Security Mobile Networks

Licentiate's Thesis submitted in partial fulfilment of the requirements for the degree of Licentiate of Science in Technology.

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Abstract of the Licentiate's Thesis

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The study seeks answer to the question of how to fulfil the future needs of the PSS (Public Safety and Security) mobile communication. The contemporary mainstream technology, TETRA (Terrestrial Trunked Radio), is chosen as the scenario starting point when defining the roadmap of the communication network for the PSS agencies. The research is based on the systematic scenario planning method. Using the scenario planning method, and being based on the identified change forces, four future scenarios are defined, the timescale being the next ten years. According to the defined scenarios, alternative strategies for the network operators are proposed. The scenarios and their match with the strategies suggest the following conclusions: (1) emergency agencies need a dedicated network, the commercial BB (broadband) cellular network is a feasible solution for non-critical data transmission; (2) the radio spectrum needs to be allocated for WB (wideband) in the <470MHz area and for BB in the <1GHz area; (3) the WB data network (50…200kbit/s) is an economical high speed mobile data solution in rural areas; (4) in future, PSS networks will consist of a set of technologies with appropriate coverage and capacity and; (5) LTE (Long Term Evolution) technology is a feasible solution for PSS BB mobile communication. Further research is, however, needed in the areas of data compression, traffic loading dynamics in the shared LTE network, security as well as on the definition of the optimum return on investment ratio from the perspective of society.

Keywords: development of PSS networks, scenario planning, TETRA

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Tutkimuksella haetaan vastausta kysymykseen, millainen viranomaisradioverkko täyttää käyttäjien tulevaisuuden tarpeet seuraavan 10 vuoden tähtäimellä. Tutkimuksen lähtökohtana on nykyisen radioverkon toteutus TETRA-tekniikalla. Tutkimus perustuu skenaariosuunnittelu–menetelmän käyttöön. Muutosvoimiin pohjautuen, skenaariosuunnittelua käyttäen, määritellään neljä skenaariota. Skenaarioiden perusteella laaditaan vaihtoehtoiset strategiat, tavoitteena optimaalinen strategia viranomaisradioverkko-operaattorille. Skenaarioiden ja strategioiden pohjalta tehdään seuraavat johtopäätökset: (1) viranomaiset tarvitsevat oman, erillisen radioverkon, kaupallista leveäkaistaverkkoa voidaan käyttää ei-kriittisen datan siirtoon; (2) uusia radiotaajuuksia tarvitaan laajakaistapalvelujen toteuttamiseksi <470 MHz:n alueelta ja leveäkaistapalvelujen toteuttamiseksi alle 1 GHz:n alueelta; (3) laajakaistaverkko (50…200kbit/s) on taloudellinen ratkaisu nopeaan datasiirtoon haja-asutus alueella; (4) tulevaisuudessa viranomaisten langattomassa tietoliikenneverkossa käytetään useita teknologioita - kapasiteetti ja kattavuus määräytyvät kunkin alueen todellisen käyttötarpeen mukaisesti ja; (5) viranomaisverkkojen leveäkaistaratkaisuksi LTE-teknologia näyttää hyvältä ratkaisulta. Lisätutkimuksia tarvitaan seuraavilta alueilta: datan tehokkaampi paketointi, jaetun LTE-verkon kuormitusdynamiikka, verkon tietoturva sekä optimaalisen hyöty/investointisuhteen selvittäminen, kun asiaa tarkastellaan yhteiskunnan kannalta.

Avainsanat: viranomaisverkkojen kehitys, skenaario suunnittelu, TETRA

Preface

This Licentiate's Thesis was done under the guidance of Department of Communications and Networking at Aalto University School of Electrical Engineering during the years 2009 - 2010. My earlier works in Nokia Networks and in EADS Secure Networks – as well as discussions and debates there with my many colleagues - have provided the perfect background for this thesis.

I would like warmly thank my supervising professor Heikki Hämmäinen, who not only guided me through this thesis but also advised me in all my licentiate studies. I offer special thanks to Yrjö Pylvänäinen, who helped me to see the world through the eyes of a Public Safety and Security mobile network operator. I also wish to thank Mikko Heikkinen and Tapio Levä in Department of Communications and Networking of Aalto University for their advice about the secrets of academic research, as well as William Martin for checking the language of this research.

All the interviewees, my old business colleagues in TETRA society and friends working in the university - you allocated your valuable time to help me in my task. Based on your long experience of public safety and security networks, of telecommunications and of research work you helped me to build the basis of my study - special thanks to you all. This thesis wouldn't be possible without your support.

Finally I want to thank my wife Raili and my sons Janne and Juuso for their support and encouragement to start and finalize my licentiate graduation at my mature age.

Espoo, 22nd of April 2011.

Matti Peltola

Contents

List of Acronyms

ACCOLC	ACCess Over Load Control
APCO	Association of Public-Safety Communications Officials
AVL	Automatic Vehicle Location
BB	Broad Band
BDBOS	Bundesanstalt für den Digitalfunk der Behörden und Organisationen mit Sicherheitsaufgaben
CAPEX	Capital Expenditure
DMO	Direct Mode Operation
DSA	Dynamic Spectrum Access
EDGE	Enhanced Data rates for Global Evolution
ERC	Emergency Response Centre
ETSI	European Telecommunications Standards Institute
Facebook	tradename of Facebook Inc., a social networking website
FCC	Federal Communications Commission (USA)
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
GSM-ASCI	GSM – Advanced Speech Call Item
GSM-R	Global System for Mobile communications - Railway
ICT	Information and Communication Technology
IRC	Internet Relay Chat
LMR	Land Mobile Radio
LTE	Long Term Evolution (mobile network technology)
NB	Narrow Band
OFDM	Orthogonal Frequency Division Multiplexing

OPEX	Operational Expenditure
PAD	Packet Assembler Disassembler
PEST	Political, Economic, Social, Technological
PMR	Professional Mobile Radio
PoC	Push-to-talk over Cellular
PPDR	Public Protection and Disaster Relief
PSS	Public Safety and Security
RFID	Radio Frequency IDentification
SDR	Software Defined Radio
TC	Technical Committee
TEDS	TETRA Enhanced Data System
TETRA	TErrestrial Trunked RAdio
TETRA MoU	TETRA Memorandum of Understanding association
TETRAPOL	Narrowband PMR system (not an acronym)
TWITTER	tradename of Twitter Inc., social networking and microblogging service
UMTS	Universal Mobile Telecommunications System
WB	Wide Band
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Access Network
YouTube	tradename of YouTube LLC, a video-sharing website
3G	3rd Generation (mobile communications)

Chapter 1

Introduction

1.1 Motivation

The concepts of the existing digital mobile communications solutions for the emergency agencies – called Public Safety and Security (PSS) mobile networks[1)] - have been developed two decades ago. The air interfaces of these dedicated systems (TETRA or TETRAPOL in Europe, APCO P25 in US)[2)] target a wide coverage with a few base stations; with the narrow bandwidth they offer the group call subscriber service and are able guarantee good availability.

The emergency networks have had traditionally two fundamental requirements. Firstly almost 100% availability of service is required; the service has to be "always-on", available everywhere for the defined number of persons in all circumstances. Secondly, the security of the communication is a must – no eavesdropping, no disturbing or jamming and the integrity of the information has to be guaranteed. The existing implementations are good for the voice communication, but the high speed data cannot be supported. The problem that the specific public safety technologies have is that they are continuously several steps behind the development of the commercial cellular networks and the whole business eco system is suffering from the lack of economies of scale. Some additional, new requirements have arisen. However, 15 years ago emergency communication was superior compared to the telecommunications used by

[1)] *These networks are often known also as PPDR (Public Protection and Disaster Relief) mobile networks or PMR (Professional Mobile Networks)*

[2)] *In this study the reference technology is typically TETRA-technology* public sector. Today the IRC-Gallery and YouTube users may know more of the present emergency situation than the police patrol who is rushing to the case location. “The situation awareness” of the emergency organization is based on the information that the telecommunications system is able to form. The low speed public safety data networks are not capable of fulfilling the new requirements. The functionality and the performance of one of the PSS mobile network technologies – the TETRA technology – are broadly described by Gray (2003) and Heikkonen et. al. (2005).

The transmission of video and other new services, what the users of the emergency network (e.g. police, fire brigades, ambulance service, etc.) would like to utilize, requires high speed data capability. At the same time the new commercial services that cellular operators are offering to public subscribers are setting “milestones” and creating expectations to emergency network users. The young people have learnt to live in a totally different world of communication than the people who have been involved in the TETRA deployment. The Facebook generation people live in a world where they have “real time” touch with the surrounding world. They are used to know “in real time” where their friends are, what they are doing just now and what is everyone’s opinion of the present hot issue – they might not accept less in their daily work. The volumes of GSM terminals have made possible he production of very complicated products for commercial markets. The commercial mobile services and commercial mobile technology are challenging examples to the PSS society. In the past, development of the communication system for the emergency agencies has been quite straightforward - the systems have been technically far ahead of what the ordinary people were able to use for their own communication. Earlier the only limiting factor was the technology - today the technology itself is no more limiting. The only limitation is the availability of radio frequencies and the budget to finance the investments.

The governments are looking into alternatives to escape the high costs of what a broadband data solution would mean. The availability of frequencies for emergency usage has become an issue – the authorities sometimes prefer to generate revenues from the free spectrum rather than to give it free of charge to the emergency organizations (Doumi, 2006). However, without the additional frequencies the building of a dedicated high speed data network is impossible. The commercial operators are willing to offer the broadband service; however, there are doubts if the commercial networks can fulfil the tight availability requirements.

All in all the PSS communication service development depends on so many external factors – of which everything has its own development path - that it is challenging to see the obvious development path of emergency communication systems. This thesis will review the alternatives and tries to define a limited amount of various schedules, how to cover the new requirements over the next decade – and how we need to develop the mobile communication network solutions for the emergency agencies.

1.2 Research Problem, Aim and Scope of Research

PSS mobile networks consist of a similar mobile infra to what the cellular networks have, i.e. the main components are mobile switches, base stations, the transmission systems between switches and base stations as well as the operating and maintenance system. The specific parts that these networks have, are the dispatcher stations which are for managing the communication of the user groups. Other essential parts of the system are mobile devices, which are typically known as user terminals – either handheld or vehicle assembled. The characteristic definitions of the network are the air-interface protocol, the frequency band, the coverage and the capacity of the base station (Gray, 2003).

The main services and characteristics of PSS mobile networks - what the network is offering - are group communication, encryption services (end-to-end and air-interface encryption) and high availability. Other typical functionalities are DMO (Direct Mode Operation), which allows terminal-to-terminal communication as well as data communication inside and from and to the IP-network. The functionalities like a specific emergency call and location services are de-facto functionalities in today’s systems.

The existing data transmission capacity of the network is based on the narrowband technology, meaning data speeds of 5…20 kbit/s. The specific wideband technology has been developed for TETRA networks called TEDS (TETRA Enhanced Data System) technology, which will offer data speeds of 50…200 kbit/s. A comprehensive description of the elements and the functionality of a typical PSS mobile network, e.g. a TETRA system, are represented by Gray (2003).

The emergency agency organizations have obvious needs to update their mobile networks so that the networks can support high data transmission speeds. The needed capacity is somewhere 100…1000 kilobits per second. The wideband data bit rates e.g. 50…200 kbit/s (i.e. TEDS technology in TETRA networks) may be enough for most of the applications, even for video transmission (Vehkalahti, 2008), especially if the development of the compression technology and better storage capacity continues as strong as what we have seen in the past years.

The new applications require more bandwidth (i.e. spectrum) for data communication than that currently allocated for the existing PSS mobile systems. The existing systems - based on the tailored platforms - have been expensive to develop comparing to the volumes and the price level, what the market accepts. The solution could be - because of the lack of spectrum and because of the shortage of economies of scale - the utilization of cellular, commodity technology in the emergency agencies' communication solutions. The commercial technology could be utilized either taking advantage of the services of commercial networks or using the same technology what the commercial operators have in their network. So far the utilization of the commercial, cellular technology has not been very successful: the cellular technology solutions, like GSM-ASCI (GSM- Advanced Speech Call Item), are lacking the necessary functionality and TETRA's access capacity implementation is more economical (TETRA MoU, 2004b). Also an important functionality, the noise tolerant voice coder, is missing in GSM-ASCI. In the case of using the network services of the commercial operators, the poor availability of the service is a fundamental problem in the case of a serious emergency situation in society.

As a summary this thesis seeks the answer to the question:

> *What will the mobile network solution for PSS agencies be in ten years from now taking into account how the enhanced data communication needs can and will be*

fulfilled? At the same time, it needs bearing in mind that financial limitations, high security and availability requirements as well as the possible role of the commercial cellular networks all have to be considered in the final solution.

The research focuses on the mobile access part of the mobile network solution. The study and its results are relevant in countries which already have or are going to have TETRA system for their emergency communication. However, some references, which can be seen relevant from the study point of view, are made also to the APCO P25-system. Some reviews - and conclusions based on them - are made behind the targeted ten years scenario in the purpose to have a better view of the development over the next ten years. However, the purpose of this study is not to argue anything of the development of PSS mobile networks in the 2020s.

1.3 Research Method

In the study the alternative scenarios of future PSS networks are drafted. Based on those scenarios the possible strategies for the network operators are proposed. The scenario planning method is used - it fits the future evaluation type of researches (Schoemaker, 1993; Schoemaker, 1995; Schoemaker&Mavaddat, 2000). The scenario planning can be used to find probable development paths of any business phenomenon. The examples of the usage of the scenario planning research method are the studies of Heikkinen et. al, (2008a), Heikkinen (2008b) and Levä et. al. (2009). The foreseen trends and the uncertainties are defined based on the interviews with the appropriate stakeholders, i.e. with the organizations and the people involved with the mobile network solutions for the emergency agencies. The correlation matrix and causal loop diagrams are used to define the causal influences between the found variables of the problem. After that four future scenarios are defined according to the method. Finally, appropriate operator strategies are selected for the purpose of finding an optimum techno-economical response to the scenarios.

Chapter 2

State of the Art

2.1 Status of Dedicated Networks

Dedicated networks means networks, which are built for a specific purpose – other than for public use. Examples of dedicated networks are telecommunication networks for railways and power utilities, emergency telephone systems along the roads, telecom systems for oil, gas, power utility companies and also the radio communication of authorities and emergency agencies. The tendency, seen in the 1980s and 1990s, was that many of the dedicated networks were built using the same technology what was used in the commercial networks – the reason being the development of the digital technology as well as the will to benefit from economies of scale. The exceptions were the railways – for which GSM-R (GSM-Railway) was defined as a standard - and the networks for the emergency agencies, for which specific technologies were developed, TETRA and TETRAPOL in Europe as well as the APCO P25 -technology in North America.

Many European countries have built or are building a new network for the emergency agencies. The digital technology has brought many improvements in comparison to old public safety networks. However, the development of the cellular technology has been at the same time so fast, that e.g. TETRA and TETRAPOL have abandoned cellular technology and are no longer capable of offering the data speeds required by users in the future. The delivery volumes of the PSS networks are small from a vendor's point of view, especially when taking into account the contribution that the complex PSS network technologies require – so economies of scale is missing. The TETRA technology markets, particularly in the infra area, are dominated by two suppliers, Cassidian (earlier EADS Secure Networks) and Motorola. These two vendors have together more than half of the TETRA infra markets.

2.2 Services and Functionality

The existing public safety radio networks have been built specifically for voice communication but also to support low speed data communication. Except dedicated functionality the public safety radio networks have two fundamental requirements: the excellent availability of the system and the security of the communication – all of this with reasonable costs (Gray, 2003).
The good access availability of the network has been implemented, firstly by using a low spectrum band in the 400MHz area, so that the number of base stations stays reasonable low and still offers good coverage. Secondly, the air interface has been defined so that the group call type of communication is possible to any user who uses the same single channel. This way a few channels can fulfil the voice communication requirements of large groups or teams (Gray, 2003). The network is also economical to build and to have to cover also rural areas, where the typical communication volume is negligible. The limited number of users makes it easier to fulfil the availability requirements – only the emergency agencies and the organizations crucial to the services of the society are allowed to use the network services.

The security is implemented firstly with the authentication - only the authenticated persons are allowed to connect to the network; everyone’s identity is checked when they join. Secondly, the air interface and the end-to-end path encryptions are used to prevent eavesdropping. There has also been some discussion about the ownership of the networks, and its effect to guarantee full security and availability in all circumstances. Today all emergency networks are owned by the authorities or the ownership arrangements are such that the control of the authorities is very tight.

The TETRA networks support, in addition to voice communication, also low speed data services, like location services, photo distribution, database queries and short messaging. However, some new public safety services need higher data bitrates, wideband (50…200kbit/s) or broadband (over 500kbit/s) data transmission capacity; especially video transmission requires that. The existing narrowband systems will not be capable enough in future, the new services require more communication capacity - expectations of higher data transmission speeds are increasing all the time.

The main functionalities and the needed capacity that the users expect the public safety radio system to support are – based on the interviews (appendix 1), Carter&Jervis (2008), Motorola (2009a) and AnalysysMason (2010):

TABLE I

MAIN FUNCTIONALITES AND THEIR COMMUNICATION CAPACITY NEED IN PSS MOBILE NETWORKS

group call	narrowband data
info and alarm messaging	narrowband data
status messaging	narrowband data
e-mail	narrow/wideband data
location services	narrowband data
imaging	narrow/wideband data
database inquiry	narrowband data
video transmission	wide/broadband data ‘)
internet browsing	broadband data
mobile command and control support	wide/broadband data

‘) depends on the used compression

The functionality, like the location service, works well for a single subscriber in the narrowband network. However, the volume of the terminals, which transmit their location data, has grown so large, that the narrowband network has come close to its top performance level (Järvinen, 2010). So although the narrowband network capacity is enough for the service, the total volumes need higher bit rates. The new high speed data mobile network, a wideband or a broadband one, has to fulfil the mentioned availability and security requirements, to have the needed capacity, and to be also cost effective.

2.3 Development of Emergency Networks

Different solutions have been proposed to solve the future radio network capacity problems (Smye, 2009); in the following sections (2.6 - 2.9) four alternatives, which have been presented in the literature, have been discussed:

(1) the first alternative is to update TETRA networks with TEDS technology

(2) the second, instead of using a specific PSS solution like TETRA, is to use commercial GSM/3G technology. This can be done either by utilizing commercial technology in the specific network or by leasing communication services from commercial operators.

(3) the third option is to expand the data capacity of the existing PSS network with an additional data network based on commercial cellular network technology. Again this could be done either using the technology as such or leasing new capacity from a commercial operator

(4) the fourth option is any new technology, tailored for PSS communication purposes, like solutions based on the WiMAX (Worldwide Interoperability for Microwave Access) technology or enhanced TEDS (Nouri, 2009).

The possible additional spectrum is an essential parameter when analysing the alternatives. Also the availability of the commercial mobile networks in the case of emergency situations has to be understood when reviewing the choices. The mentioned two parameters are discussed first before reviewing the four cases.

2.4 Spectrum Considerations

In the US the shared ownership of the spectrum (and the network) of private and public entities has been seen as a preferable solution: in case of an emergency a predefined part of the spectrum would be allocated for the emergency agencies. This solution has been analysed by Lehr&Chapin (2009b) and Lehr&Jesuale (2009c). The solution is based on DSA (Dynamic Spectrum Access) and on cognitive radios. They argue that dynamic spectrum access improves the utilization of the spectrum, because, for example, the frequencies allocated for emergency agencies - which are normally unused - could now be utilized for commercial purposes. Although it might be so, someone may ask how much spare capacity there really exists. The situation may be very close to the same situation described in section 2.5, where the utilization of ACCOLC (Access Over Load Control) is discussed. The problem is that the commercial operator typically does not have so large reserves of extra capacity that in an emergency case it would be possible to drop part of the capacity away. If that will be done, the commercial customers may not accept that kind of behaviour of their network.

Carter&Jervis (2008) have made a study, where they show how important it is to allocate a part of previous analogue TV broadcasting frequencies for public safety purposes in Europe. They propose that two 15MHz blocks will be allocated somewhere in the 400…800MHz band in Pan-European width. The conclusion is that if the emergency agencies fail to obtain frequencies, the PSS communication networks are not capable of transmitting the data streams required by new services like video transmission. *Viestintävirasto* (2009) in their report of the utilization of the radio spectrum in future defines that the spectrum band of 380-400MHz has to be reserved completely for the public safety and security organizations. The new needs of the PSS organizations require spectrum reservation for WB and BB use in another spectrum band.

ETSI TC TETRA (The European Telecommunications Standards Institute TETRA Technical Committee) has made a proposal (Wählen, 2010), that three additional spectrum blocks should be allocated for PSS use, 2 x 3MHz for narrowband usage close to the existing frequency band, for instance, in the 380-470 MHz area, 2 x 3MHz for wideband usage in the 380-470 MHz area and 2 x10MHz for broadband usage in the 470…790 MHz area. Pastukh (2010) has a similar proposal (2 x 3MHz for NB (narrow band), 2 x 3MHz for WB and 2 x10MHz for BB), but defining the frequency range for all three data transmission ranges (NB, WB, BB) as 300…862 MHz. The AnalysysMason (2010) report follows the same thinking.

2.5 Availability of Commercial Networks

The major drawback of the commercial mobile networks - if they are used as radio networks for emergency agencies - is their availability in times of big disasters or large emergency situations. As mentioned, experience has shown that during all large scale emergency situations, commercial mobile networks will become blocked, because the people are calling to their relatives and friends (Lavery& Horan, 2005), (Swan&Taylor,

2003). The latest experiences have shown, that because of the wide social networking of the youth (TWITTER, IRC-Gallery) and the use of mobile Internet, the commercial networks have become even more sensitive to any size of emergency in society, including even small fire accidents, car collisions, etc. (*Suomen Erillisverkot*, 2010b). The priority rights of using the commercial mobile network can be given to the authorities: in UK, for example, it can be done by ACCOLC. ACCOLC is a procedure for restricting the usage during times of emergencies (Lavery & Horan, 2005) **–** i.e. only those persons who have the authority have access to the mobile network. However, the activation of ACCOLC is a risk, because it may cause the overloading of the emergence response centre, if emergency service calls are still aloud to ordinary subscribers. It is also questionable whether mobile subscribers will accept an operator service which will be blocked during a serious emergency - if they have an alternative operator to choose (NPIA, 2009). In some terrorist attack cases the authorities have considered to close the whole cellular network in the purpose to prevent the utilization of the network for the remote activation of the explosive charges.

The idea to block the public telephone service - either mobile or fixed or both - if the serious emergency event is on, is someway contradictory to the new culture, where a lot of actual information of phenomena, accidents and incidents is reported by the individuals to the authorities and also often to broadcasting radio stations. The high density of mobile phone users has created this culture and made it happen. The other cultural issue is that people are more and more used to access the Internet using their mobile devices and in this way are used being updated of “situation awareness”. The jamming of a cellular base station by creating an abnormal number of calls is an illegal trick and would be possible in rural areas where the number of channels per base station is low. This is one of the risks which can occur if the commercial network is used for public safety purposes.

2.6 Update of TETRA Networks Using TEDS Technology

TEDS is an expansion of the TETRA standard (Nouri et al., 2006). The technology is the wideband solution for TETRA networks, offering bit rates from 50kbit/s to

200kbit/s in practical implementations. Many countries see TEDS as a potential next step to improve the performance of the data communication in TETRA networks. Some commercial agreements have already been signed, Norway, for instance, has ordered TEDS functionality (Motorola, 2008). TEDS offers the economical solution to increase a TETRA network's data transmission capabilities (Motorola, 2009a). Depending on the chosen modulation scheme, the same base station sites may be used.

2.7 Replacement of TETRA Solution with Commercial Technologies

Cellular mobile radio based technologies have been proposed for use in public safety radio networks to replace TETRA or other PSS mobile network technologies. GSM-ASCI has been proposed to be a new solution, and also 3G and LTE based on PoC (Push-to-talk over Cellular) have been argued to be a good solution for future PSS mobile technologies.

GSM ASCI

The possibilities to use GSM based technology in public safety radio networks have been quite comprehensively studied by Riesen (2003). He has compared GSM-ASCI and TETRA solutions technically and financially and come to the conclusion that TETRA is the better alternative in both instances.

When the procurements of national PSS mobile network were in process in Norway and in Germany, studies about the possible utilization of cellular solutions were made (NEXIA, 2002; Gartner, 2002; Bretschneider, 2004). Both countries decided to select TETRA technology. GSM-ASCI is based on a "commercial platform" and because of that, it could be an economical solution, however, it has several drawbacks. TETRA MoU's (2004b) article makes a deep analysis of GSM-ASCI capability as a public safety communication system. The conclusion is that GSM-ASCI "have functional deficiencies" compared to the requirements defined by public safety organizations. The other main concerns are the massive channel capacity that public safety operations might require (Heikkonen et. al., 2005) and concerns over the remarkable redesign work that terminal vendors should do. GSM-R is a practical example of the use of a modified cellular technology. GSM-R is a technology, which is based on GSM-ASCI, but includes some additional features for railways.

UMTS and LTE solutions based on Push-to-talk over Cellular (PoC)

Ericsson's White Paper (2006) describes the solution which follows the principles of service-oriented architecture, PoC and 2G/3G technology. The article goes into few details, however some further development are reported comparing to the GSM-ASCI based solution, especially the richer functionality can be offered. The drawback in the analysis is the poor performance of the system (500ms call establishment time in group calls required) – the described solution cannot fulfil this.

TETRA MoU's (2004a) article analyses the utilization of PoC technology in public safety solutions. The conclusion is that although PoC is a new way to implement the group communication in the cellular networks and PoC fulfils the basic needs to perform the group call function, its performance does not fulfil the mission critical communication requirement. Some functionality is still missing and the problem of the behaviour of the public networks during the emergency situations is still the same.

Blom et al. (2008) have analysed further the utilization of commercial cellular technologies - especially EDGE (Enhanced Data rates for Global Evolution) and WCDMA (Wideband Code Division Multiple Access) - in public safety communication. The newest solutions have improved the latency time, such as the time when the tangent has been pressed on the phone until the moment when the speech connection is on. In public safety communication this time has to be less than 500 ms (Gray, 2003). Even the performance has been improved as there are still issues to solve, for instance the channel delay. Also the case, when there is a large number of PSS mobile network users in the same area, seems to need special arrangements remembering that this kind of situation can - from an operations point of view - stands up very fast.

In Sundkvist’s (2008) analysis the main target is to understand the LTE’s cell capacity on group communication with a voice service. He shows that LTE can serve large groups for communication. An issue that the cellular technologies (GSM, GPRS (General Packet Radio Service), EDGE, 3G) have when trying to complete the PSS voice communication requirements, is the long delays in the call setup times. According to NSN (2010), LTE will fulfil the required 500ms call setup time, the same conclusion was made by Motorola (2009) when specifying the latency time of LTE. The LTE technology is capable of sharing the capacity of the same network elements between the different operators. This functionality may have an impact on investment costs also in possible LTE PSS solutions, if the overall availability can be secured. The issue, which LTE also has, is the need for a large number of PSS voice communication specific functionalities which must be implemented before LTE can be used for voice communication by the emergency agencies – and at the same time the expected market volumes stay quite low (NSN, 2010).

2.8 Commercial Technology Used to Expand Data Capacity of the Networks

The third solution is to have a separate network for the voice plus low-speed data communication and the WB/BB data network for high speed data services; the later one having lighter availability requirements than which the voice communication requires.

Networks architecture considerations

Ittner (2006) presents an architecture concept of public safety radio networks, which has four layers (fig. 1). The basic layer is the traditional public safety and security radio with low bit rate data capacity, i.e. the narrow band network; this network covers the whole country. The second layer is a wideband data network (data bit rate 50…200kbit/s); the WB network shares the same base station sites with the narrow band network. The WB is not covering the whole country, remote areas left out. The third layer is a broadband network (bit rate >500kbit/s). Because the coverage of the BB base station is smaller than the previous ones, the BB network needs dedicated base station sites. The BB network covers the cities and suburban areas. The fourth layer is made of ad hoc networks, which are established whenever there is a need for that, such

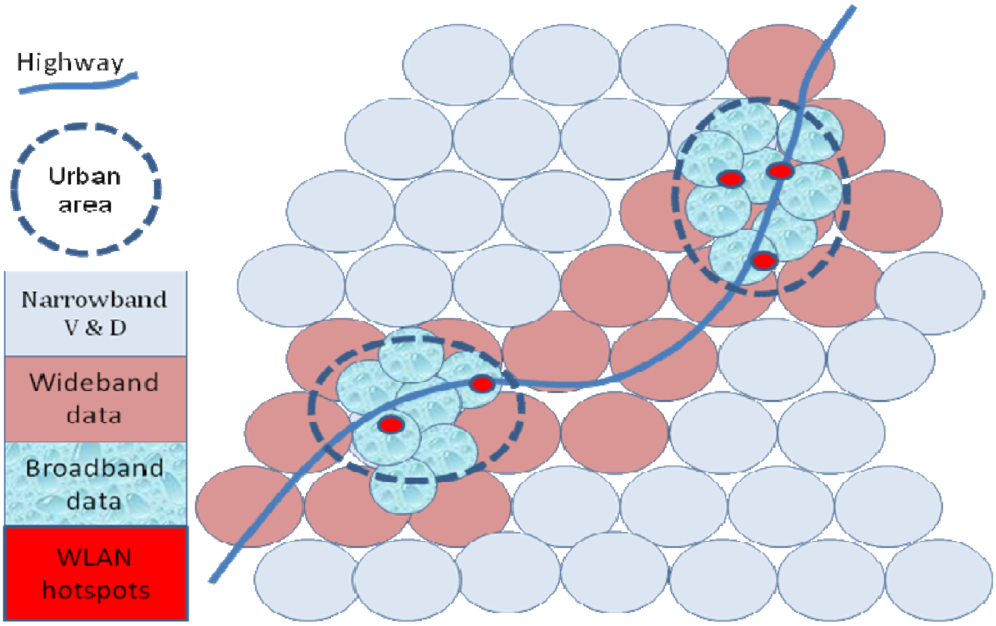

Fig. 1. Economical Coverage with Heterogeneous Networks
(according to Ittner, 2006)

as within big events or large incidents. The used technology can be, for example, WLAN (Wireless Local Access Network).

Ittner's (2006) approach is a hybrid solution. The investment volume follows the population density figures. This approach gives good added value counted per investment and per citizen. The described architecture targets the optimum within investment, requirements and systems capabilities. Lehr (2009a) comments on the heterogeneous architecture with the words: "The future will not be composed of a single wireless network or technology. Rather there are likely to be a range of capabilities, and implemented using many protocols and architectures". Doumi's (2006) article follows the same architecture thinking.

Overlay networks

The technologies used to build the additional data network are several. GSM/3G can be used; the usage of GSM network as an additional communication tool for the police forces was indicated in the interviews (Appendix 1). The 3G and Flash-OFDM/450 (Flash-Orthogonal Frequency Division Multiplexing/450MHz) technologies are used to build broadband data networks. The other solution, what is mentioned, is to base the infra solution on the WLAN network in the urban area; such a solution has already been implemented in New Orleans (Korver, 2008). This alternative would offer broadband services only in urban areas – which, however, may sometimes be acceptable. Bastos&Wietgrefe (2007) describes the tests, where a mission critical trial network was implemented using WiMAX technology. Doumi (2006) in his article prefers 3G as a wide area broadband solution and WLAN as a solution for ad hoc networks. Also the femtocell technology could be used as a solution for ad hoc networks (Chandrasekhar et. al., 2008). In the United States the LTE technology is seen as the most probable technology which will be used when implementing the high speed data network for PSS users (Hallahan&Peha, 2010; Motorola, 2009b; Motorola, 2010).

2.9 New Specific PSS Communication Technologies

The main challenge that the new specific PSS communication technologies all have is the missing of economies of scale. It's said earlier, the volumes compared to the cellular technologies are negligible. For this reason there have been only a few plans to develop new technologies specifically for the emergency agencies.

ETSI TETRA Working Group 4 has presented thoughts to improve TEDS performance by using higher level modulation or more efficient channel coding, a so called enhanced TEDS (Nouri, 2008; Nouri, 2009). Also new antenna techniques have been mentioned.

The WiMAX based solutions have been seen as a possible platform for the future PSS radio system. Bastos&Wietgrefe (2007) describe a WiMAX based, mission-critical communication system for military purposes. The mobile WiMAX, however, has no technological advantage compared to the LTE technology and WiMAX's commercial possibilities to win a significant market share are weak (*Liikenne- ja viestintäministeriö*, 2009a). I.e. if the existing PSS technologies are suffering from low volumes, it seems that the utilization of the WiMAX technology will not give any advantage.

The cognitive radio technology could be a way to develop new public safety systems. As already said this alternative has been discussed by Lehr&Chapin (2009b) and

Lehr&Jesuale (2009c). The important part of this implementation is the development of SDR (Software Defined Radio) technology.

2.10 Economics Feasibility

Some studies, which analyse the possibility to utilize commercial networks for public safety purposes, argue that there are economical benefits of using commercial networks (NEXIA, 2002); others prove the conclusion to be exactly the opposite (Gartner, 2002). Saijonmaa (2009) has studied the costs of building and operating a high speed data radio network (an overlay network) for public safety purposes; he has analysed two cases: to upgrade the current TETRA network with TEDS technology or to build a separate high-speed data network using the GPRS and EDGE technologies.

The reference point in his study is the price of the commercial EDGE data service. The guaranteed service requirements means higher prices than normal subscribers are currently used to pay. In Saijonmaa's (2009) study the price estimates are for data service 15€ … 60€/month/user and for AVL (Automatic Vehicle Location) tracking 10…100€/month/user. However, the prices what he uses in his examples are conservative, i.e. total 35€/per user/per month (the high speed packet data service 15€, AVL tracking 20€).

The cost calculations for the upgrade of the existing TETRA network to TEDS network show, that if there are more than 35 users per base station site area, then TEDS is a feasible solution based on the mentioned tariffs (the average user density in Europe is 20…80 users). If only OPEX (Operational Expenditure) costs are taking account, the TEDS solution is feasible if there are 20 users per base station site. The similar calculation shows that the building of a separate GPRS and EDGE service requires that there are more than 80 users per base station site area before GPRS/EDGE is feasible.

The conclusion of Saijonmaa's study (2009) is that, if the commercial operator can sell a high-speed data service for a user fee of 35€ per month (including AVL services as well as the service availability guarantee), then the commercial service is an economical solution until the point where the number of users grows higher than 20…35 per base station site. If the number of users is higher, then a TEDS solution is more feasible. If the price of the reliable service offering is higher than 35€, then the breakeven point (i.e. number of users per base station site) goes down. If the number of users per base station site is higher than 80, then the building of a dedicated GPRS/EDGE network is feasible comparing to the case where this service is bought from commercial operators.

Motorola's white paper (Motorola, 2009a) represents the results of the simulation, made in UK, where they have studied the most economical WB data network for emergency agencies, i.e. GPRS/3G or TEDS. The GPRS/3G network service is purchased from the commercial operators based on the existing commercial networks. The TEDS networks service is based on the assumption that TEDS can be rolled-out just by upgrading the existing TETRA network, i.e. by installing the TEDS capable transceiver equipment with the upgrade of the network software. The calculated total cost of ownership includes all costs, covering also terminal costs – the amortization period in the calculations is 7 years. The GPRS and 3G costs are estimated according to the market end-user prices in Western Europe. The indicative costs in the TEDS case were 10…14 dollars per user and per month depending on the location, i.e. urban, suburban or rural area. The corresponding costs in the GPRS/3G case were 52 dollars in the simulation that was made. The conclusion was that the dedicated TEDS system is at least 70% cheaper than buying the WB data service from the commercial operator.

Hallahan&Peha (2010) have studied the costs of the various alternatives of the nationwide public safety wireless network in the United States. They show that the cost estimates can change dramatically by adjusting a few input parameters. The greatest impact comes from the used frequency band, but also the parameters like coverage area signal reliability, building penetration margin, required aggregate capacity, required highest user data rate and population/area build-out requirements have a major impact on the investment and operating costs. The main conclusion of their study is that in the United States the common PSS network is more economical than the existing fragmented approach. When comparing the total 10 years costs of (1) *the public-private partnership voice+data network* with the costs of (2) *the public-safety-only data network plus the separate voice only safety network*, the cost differences were marginal.

The public-private partnership has been a plan what FCC (Federal Communications Commission) has tried to implement to get a nationwide BB network to be built in the United States. So far (2010) the planned auction to sell a frequency band in the 700 MHz area has not been successful (FCC, 2010).

2.11 Terminals

Three suppliers (Cassidian[5], Motorola and Sepura) are dominating the terminal markets. However, the volumes are negligible compared to the cellular phone volumes. TETRA terminals have been able to benefit from the platform development of the cellular phones, but overall, the benefits between the two technologies have been minimal. R&D investments have been huge compared to the annual business volumes - and still the technology gap between the cellular terminals and PSS phones seems to increase. At the same time PSS terminal vendors try to follow all ICT (Information and Communication Technology) innovations and fulfil the PSS communication network users’ wish list for intrinsic, robustness terminals as well as different ancillaries like headsets and vehicle radio equipment. The terminals supporting the applications, which utilize the high-speed data connections, have their own requirements, i.e. there may be a need for a specific PAD (Packet Assembler Disassembler) terminal. All in all, the PSS products, the vendors and customers form an eco system, where all parts have to fit together logically. The development of any fundamental new part means the restructuring of the whole business model.

Chapter 3

Research Method: Scenario Planning Reviewed with Strategy Alternatives

In this chapter the research method is described. The research process has two main steps: (1) the use of the scenario planning process to define the scenarios and (2) the definition of strategies on the scenarios. Alternative scenarios of the coming future are defined by using scenario planning (Schoemaker et. al., 2000) which does not try to find a single solution, but a limited number of future alternatives. After the scenarios have been defined, Porter's (1985) five strategy process will be used. The overall research method is described in Fig. 2.

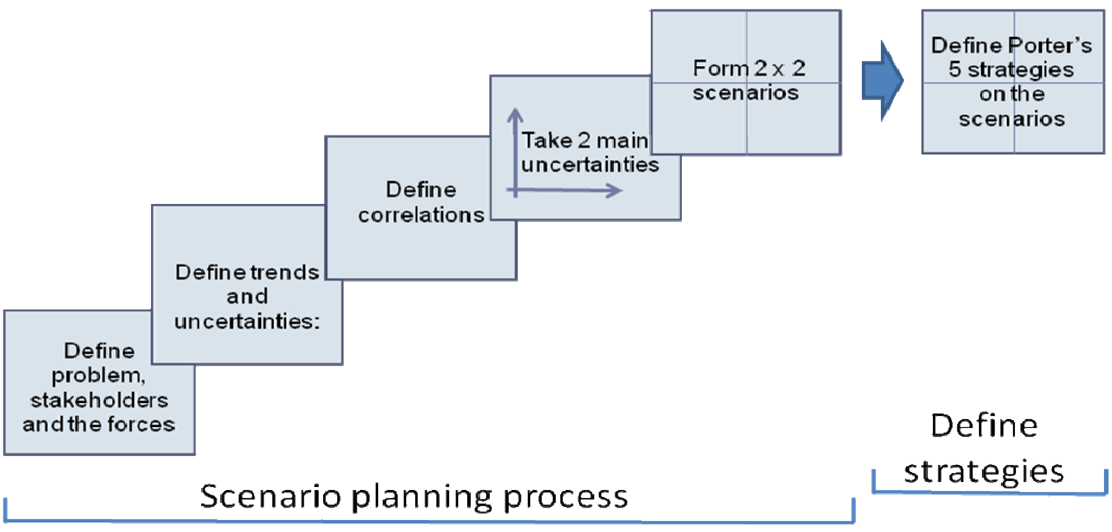

Fig. 2. Research method diagram

3.1 Scenario Planning Method Used to Find Future Alternatives

The scenario planning method (Fig. 3), defined by Schoemaker et. al. (2000), is used in this study to form scenarios of the future PSS mobile networks. The method has been used widely to solve similar future problems, see for example Heikkinen et. al. (2008a), Heikkinen (2008b) and Levä et. al. (2009).

Define problem

The first step is to define the problem more in detail, the time frame, the scope of the study and the decision variables.

Define stakeholders

The stakeholders or actors, including their power to effect, are defined. The understanding of the stakeholders is important in the next phase, when the forces, which are potential trends or uncertainties, are defined.

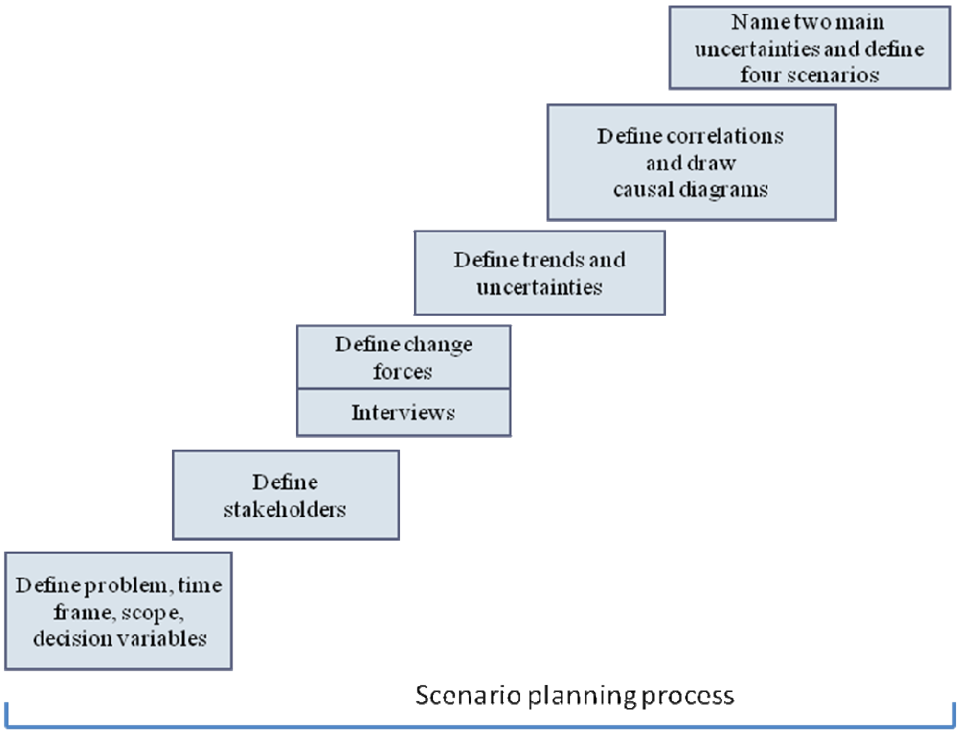

Fig. 3. Scenario planning method diagram

Define change forces by interviews

The change forces, which may change the future, are listed. The named forces are also scored in terms of importance and predictability. This part is done in the interviews of the stakeholders of PSS mobile communications. The purpose of the interviews is to find the main forces which are affecting the development of the Public Safety and Security networks and also to find how strong and predictable these forces are. The inquiries are done by interviewing professionals of the telecommunication industry and people involved with public safety networks operations.

Define trends and uncertainties

The trends and uncertainties are named of those forces, which are found during the interviews. The forces which have high importance and high predictability are named as trends. The forces having high importance and low predictability are referred to as uncertainties.

Define correlations and draw causal diagrams

In the next step the correlations between the uncertainties are checked by making a matrix where the mutual correlations of the main uncertainties are listed. After that the causalities (Sterman, 2000) of the main uncertainties are drawn to understand better the relationships between the uncertainties. This gives a deeper understanding and defines the role of uncertainties in the structure of the studied problem.

Name two main uncertainties and define four scenarios

Based on the causal loop diagram and the strongest correlations the two most important uncertainties can be selected. Two key uncertainties can be used to form a two-by-two matrix, where each of four cells will be a core of a scenario. The suitable outcomes of other uncertainties and the trends are then added to complete the scenarios. Based on this information the final scenarios are defined and described. The whole scenario planning process is well described by Schoemaker et. al. (2000).

3.2 Defining Six Strategies based on Scenarios

The truthfulness and probability of the found scenarios could be clarified with quantitative analysis. However, it would be complicated to perform and not necessarily reliable. Instead of that, the scenarios are tested using them as input data for the strategy planning according to Porter (1985). Porter says that “there are five basic approaches to dealing with uncertainty in strategy selection when a firm faces plausible scenarios with differing strategic implications”.

The five strategy alternatives are: (1) a strategy based on the most probable scenario, (2) a strategy based on the best scenario, (3) a hedge strategy, i.e. protect yourself to be ready for all scenario alternatives, (4) a preserve flexibility strategy, i.e. wait and see what will happen and (5) an influence strategy, i.e. influence the causal factors, which are behind the favourable scenario variables.

The developed sixth strategy is a combination or a conclusion of the listed five strategies.

Chapter 4

Defining Change Forces

4.1 Stakeholders

The stakeholders form a value network, i.e. a set of interlinked stakeholders who work together to create economic value through services and products (Casey et. al., 2010). In the following the stakeholders are defined in two extreme cases: (1) the PSS mobile network is owned and operated by the government and (2) the government purchases the full PSS mobile service from a commercial mobile operator, who uses the commercial network to provide the service. The latter alternative is not used anywhere in Europe, but it is taken as another reference, because it can be seen as the outmost alternative to the traditional execution of the PSS mobile network service.

In the PSS mobile value network the stakeholder[3], who is responsible for the ownership, financing and service requirements, is the emergency services administration, i.e. the government. The standardization bodies like ETSI and the TETRA Forum are stakeholders to specify the systems. The regulator allocates operator licenses and spectrum as well as may set competition rules. The user group actors (police, fire, ambulance, emergency response centre) are using the services of PSS communication. The defence forces are an important user group in those countries where they utilize the PSS mobile network. The network service operators are actors who are responsible for building, operating and maintaining the technical PSS network. The suppliers of the network equipment, terminal manufacturers, application developers and system

[3]) *Stakeholders are also called as actors.*

integrators are stakeholders to implement the functionality of the service. The commercial cellular operators are also often actors of the PSS mobile networks; they often supply BB services for the office type of communication using their existing commercial networks. In some countries private operators lease base station sites or trunk capacity for the PSS mobile network. If the PSS mobile communication service would be based on the usage of the commercial mobile network, then the role of the operator as a stakeholder would be strong.

The business issue, when providing the PSS mobile network services, is: “How to supply with minimum costs the mobile network service, which works in all emergency situations, offers required voice and data communication capacity – and fulfils specific PSS requirements including security and availability”. The main difference in business cases of the PSS mobile network and of the commercial mobile network is that in the PSS case the main issue is the secured coverage in all circumstances, not the capacity like in the commercial networks. The number of users in the PSS mobile network is typically only a few percent of the number of subscribers in a commercial mobile network as can be seen in Table III.

Figure 4 represents the value network models in a common case, where the dedicated PSS mobile network is owned by the government. In this alternative the contractual relationship from the government’s point of view is very wide (shadowed background).

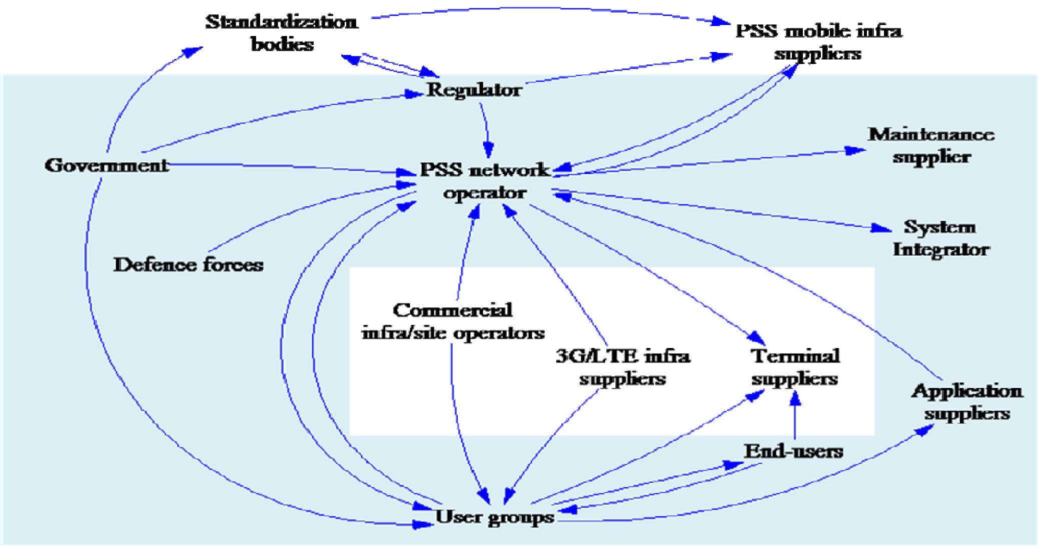

Fig. 4. Stakeholders – the dedicated PSS mobile network

Figure 5 represents the case, where the PSS mobile communication services are bought from the commercial mobile network. In this case the main contractual link is between the government and the operator. As said earlier this alternative is not used in Europe (Table II). The reason is the conflict between the requirements of two stakeholder groups (shown with the dotted lines in Fig. 5) – the government with the defence forces has high availability requirements during emergency cases, which in practise would require limiting the access rights of ordinary subscribers (see Fig. 5).

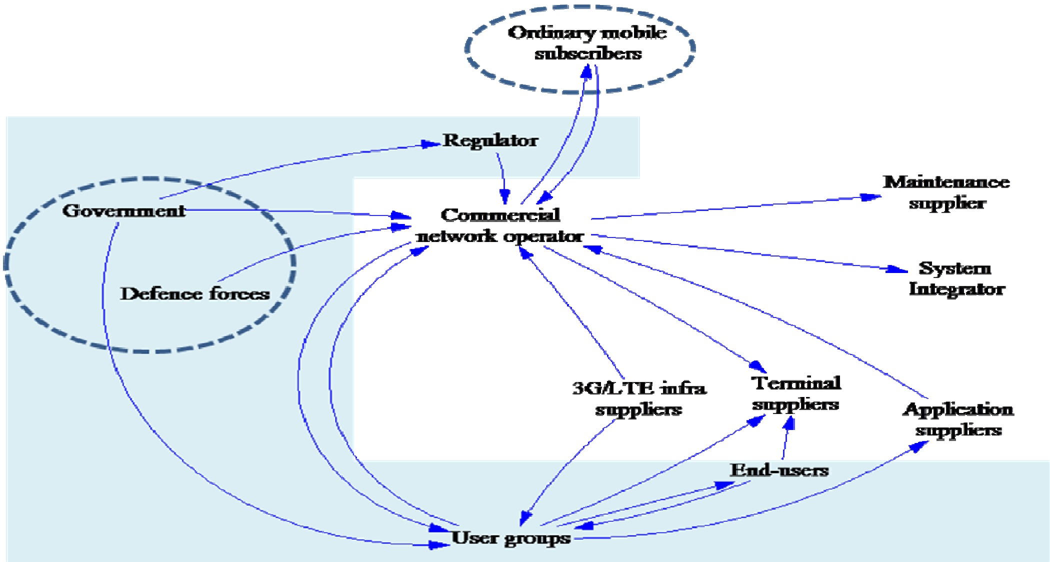

Fig. 5. Stakeholders – PSS mobile services offered by a commercial mobile network

4.2 PSS Mobile Network Cases in Europe

The deployment of PMR (TETRA or TETRAPOL) narrowband PSS networks in the western part of Europe is represented in Fig. 6. As it can be seen from the figure, almost every European country has decided to build a dedicated nationwide PSS network. The date when operations commenced (Table III) has a wide variation (2001…2010) and some countries are even still planning the network.

Today the nature of the business models in PSS network operations varies only slightly in Europe - there are some differences in the ownerships, in technical network operations and in network maintenance responsibilities, as can be seen in Table II. The table III lists basic parameters of some European PSS networks. The number of users

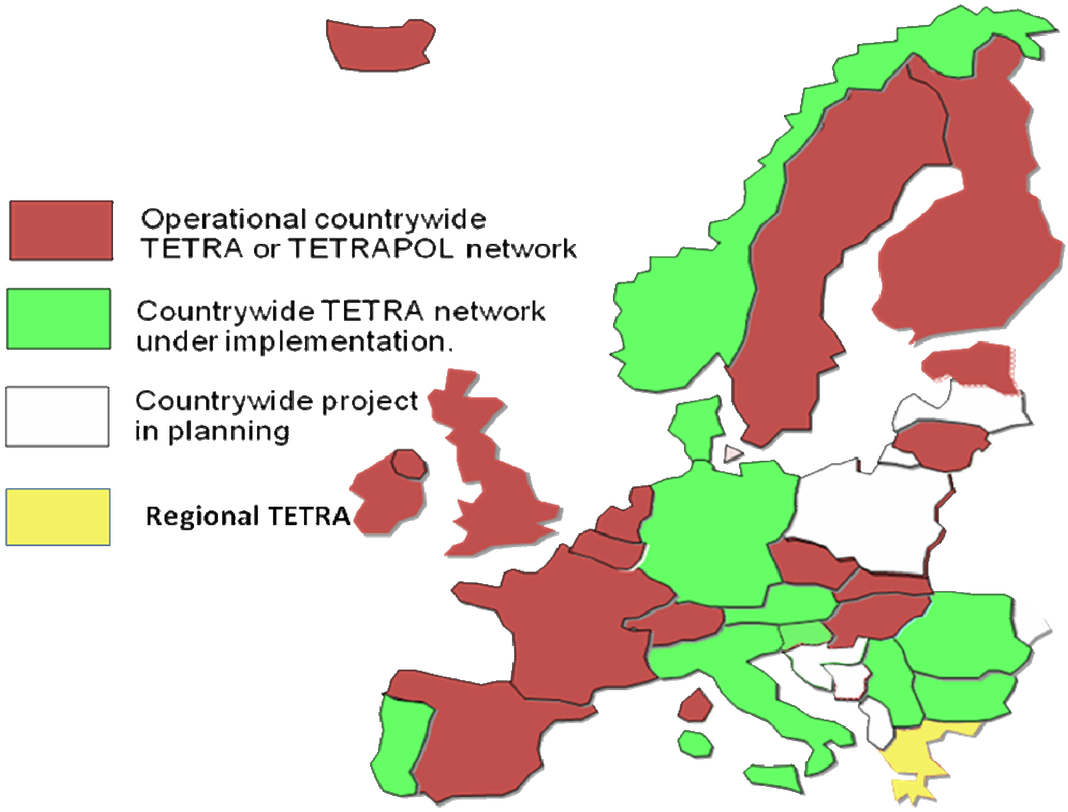

Fig. 6. Deployment of PMR (TETRA or TETRAPOL) narrowband PSS networks in the western part of Europe (Nouri, 2008; Interviews, Appendix I).

and base stations are the expected figures in the beginning of the project. The original CAPEX (Capital Expenditure) is the costs of the investments and the implementation, which were planned when the project was started. In many networks the radio coverage has been improved since the original plans, but the costs of the charges are not typically available. In four different cases the roles of the ownership and responsibilities of the operation are described in more details, the key figures of the cases are shown in Table III.

Case Belgium

The PSS network in Belgium, called as “ASTRID”, is owned and operated by the limited company A.S.T.R.I.D., owned by the Belgium government, founded in 1998 (ASTRID, 2010b). The delivery of the TETRA PSS network was awarded to the KNT consortium (Kreutler-Nokia-Telindus) for the provision of a radio network, provincial control rooms and end-user devices. The operator owns the base station sites and the transmission links between the base stations and mobile exchanges. The service was

TABLE II
OWNERSHIP, TECHNICAL OPERATION AND MAINTENANCE ARRANGEMENTS OF PSS NETWORKS IN SOME EUROPEAN COUNTRIES

Country	**Ownership**	**Technical operation**	**Maintenance**
Austria	Private company[4]	Private company	Private company
Belgium	Government owned company	Government owned company	Private company
Estonia	Government	Government owned company	Government owned company
Finland	Government	Government owned company	Private company
France	Government	Government	Government
Germany	Government	Private company	Private company
Hungary	Private company[4]	Private company	Private company
Netherlands	Government	Government owned company	Government owned company
Norway	Government	Private company	Private company
Spain	Private company[4]	Private company	Private company
Sweden	Government	Private company	Private company
UK	Private company[4]	Private company	Private company

4) If the network is owned by a private company, there are strict restrictions set by the government concerning the ownership arrangements and the service level requirements; in these cases the network is dedicated only for the use of PSS organizations.

control rooms and end-user devices. The operator owns the base station sites and the transmission links between the base stations and mobile exchanges. The service was opened in 2003. The first level maintenance is taken care by the A.S.T.R.I.D., the other levels by the KNT consortium. There are 11 provincial control rooms in ASTRID's network and on an average day (in 2008) half a million conversations are held via the ASTRID network.

Case Finland

The PSS mobile network of Finland, known as "VIRVE", is the first TETRA network in the world and it covers the whole country. The network was delivered by Nokia, and later updated by EADS Secure Networks[5]. The network is owned and operated by Suomen Erillisverkot Oy, which is owned by the Finnish government. Initially the

5) EADS Secure Networks changed its names as Cassidian in 2010

TABLE III
FACTS AND FIGURES [6,7]
OF PSS NETWORKS IN SOME EUROPEAN COUNTRIES

Country	**Nbr of users**	**Orig. nbr of basestations**	**Original CAPEX[6]**	**CAPEX /basest.**	**Operation started**	**Other comments**
Belgium	50.000	500	-	-	2003	
Estonia	10.000	125	12 M€	96k€	2007	
Finland	31.000	1200	134 M€	112k€	2001	
France, Acropol	45.000	390	500 M€	1282k€		*Covering a part of the country*
Germany	500.000	4500	~1000 M€	222k€	First part 2009	*Construction ongoing*
Hong Kong	12.000	110	91 M€	83k€	2004	
Nether-lands	80.000	550	-	-		
Norway	37.000	-	~400 M€	-	First part 2010	*Construction ongoing, includes ERC costs*
Sweden	50.000-70.000	1700	250 M€	147k€	2006	
UK	250.000	3500	950 M€	270k€	2001	

6) Sources: Interviews (Appendix 1), dNk (2010), Juurakko (2003)
7) The reasons for the large variety of costs are often the different ownership or contractual arrangements in site costs (land, building, mast, power supply, batteries) and in the transmission link arrangements (own or leased link) (Juurakko, 2003).

network was built utilizing Sonera’s base station sites and transmission links as well as the maintenance service supplied by Sonera. This arrangement led originally to low investment and low operations costs. Later, after Sonera’s public offering and when Sonera was acquired by Telia, the network infra has become less dependent on one operator. The network transmits 3.6 million calls and short messages per day (Suomen Erillisverkot, 2010b).

Case Germany

The PSS mobile network of Germany, called “BOSNet”, will cover the whole country. The delivery of TETRA network was awarded to EADS Secure Networks. The network is owned by the German government. The Federal Agency for Digital Radio of Security Authorities and Organisations (BDBOS) is managing the network (BDBOS, 2010). The task of the BDBOS is to set up, operate and ensure the operability of a digital voice and data communication system. The implementation has been done with the commercial operator Vodafone by utilizing the existing base station sites. The operation and maintenance agreement has been done with Alcatel-Lucent.

Case UK

The TETRA PSS mobile network of UK covers the whole country. The network is owned and operated by Airwave, which is a private company; however, the government has to right to accept or to reject possible new owners of the company. During its existence, the ownership of Airwave has been changed four times. The network is delivered by Motorola. Airwave was originally owned by British Telecom – based on that background most of its base station sites and transmission links are owned by BT and then leased by Airwave. Airwave has a 15-year agreement with the UK government for the PSS mobile communication services. The first agreements (first counties) will end in 2016; after the agreement expires the government is free to buy the service from anyone (NPIA, 2009).

4.3 Analysis of Main Stakeholders

In the following the short form analysis has been done of the key stakeholders (ref. Fig. 4 and Fig. 5) by reviewing the interests, alternatives, pros and cons of each stakeholder.

Government

Interests	Purchase the mobile communication service for the emergency agencies – the service, which is secured and available in all circumstances.
Alternatives	(1) Own and operate the network by self, (2) own the network and buy operation and/or maintenance services from outside, or buy the whole service from the commercial operator. In the later case there are two alternatives, either (3) the network is dedicated for PSS agencies or (4) the commercial network is used to produce this service.
Pros	There is a lot of information of the behaviour of PSS and commercial mobile networks in the case of the emergency situations – this works as a guideline when defining the communication alternatives.

Cons	The dedicated technology (infra and terminals) is not able to follow the development of the technology and suffer of the low market volumes. Reliability of the service has to be guaranteed – this may be a challenge to the commercial operators. The changes in the operator ownership form a risk.

Regulator

Interests	Allocate spectrum and the operator licence so that the decision is optimum to the whole society. The regulator also sets some competition rules.
Alternatives	The main alternatives are spectrum allocation decisions. The proposal is made to ETSI that the following bands will be allocated for PSS use in Europe: - additional 3+3 MHz for narrow band, and - 3+3 MHz for wideband communication, both in the area of 380…470 MHz, - 10+10 MHz for the broadband communication in the area of <790MHz. Commercial operators are naturally also interested in the same bands. The most valuable spectrum is in the low frequencies because the coverage can be implemented with fewer base stations.
Pros	The digitalization of the television frees the frequencies in the listed bands.
Cons	The decisions should be harmonized in Europe, otherwise market volumes will stay low.

PSS network operator

Interests	Supply the mobile communication service for the emergency agencies – the service, which is secured and available in all circumstances. New spectrum is needed for WB and BB services. Save the made TETRA investments, build a WB network using the same base stations what TETRA uses (i.e. in the frequency band

	<470MHz), build BB network in the band <1GHz,
Alternatives	(1) Own, operate and maintain the network by itself, (2) own the network and buy operation and/or maintenance services outside.
Pros	The high availability of PSS mobile networks.
Cons	Spectrum allocation.

Commercial cellular operators

Interests	Utilize the existing network and with marginal additional investment and operations costs to supply the mobile communication service for PSS agencies. The monthly fees of the PSS agencies may be higher comparing to the traditional ARPU fees.
Alternatives	There are 3 alternatives: (1) the network is a commercial cellular network and PSS agencies use that network; (2) the operator has a dedicated network for PSS agencies or; (3) the network is owned by the government and the cellular operator sells operation and/or maintenance services.
Pros	In the listed alternatives the offering of the service using the commercial cellular network, gives largest incomes. The network coverage is good.
Cons	The risk management. The network capacity during the emergency cases has been insufficient. The update of the commercial network so that it fulfils the battery backup and repair response time requirements may be expensive. Also possible remedy fees in the contract may be too high.

User groups

Interests	The user groups (police, fire, ambulance, emergency response centre, boarder guard, customs, etc.) want to have a secured, reliable mobile communication system, having specific PSS type functionalities and which also offers as much as possible similar services what the commercial mobile networks can provide.
Alternatives	User groups can and will utilize in their daily work, except the PSS

	mobile network, also commercial cellular networks using their own cellular phone or the one owned by their employer.
Pros	The dedicated PSS mobile networks are shown to be reliable communication tools.
Cons	The dedicated solutions (infra and terminals) are not able to follow the development of the cellular technology. The reliability and the availability of the commercial network are unsure.

PSS network equipment supplier

Interests	PSS mobile communication is a low volume, niche market in the telecommunications area, where the margins are slightly higher than in the traditional cellular equipment business. The high speed data communication needs will open new opportunities.
Alternatives	The last big TETRA networks in Europe will be ready in about the year 2015, i.e. the TETRA technology support and updates are needed until the end of the 2020s. TEDS is TETRA compatible wideband technology and may be the most economical solution in rural areas. The PSS BB solution is most probably based on the commercial technologies, likely on LTE.
Pros	Many countries have plans to offer WB/BB mobile communication service for their PSS agencies.
Cons	In the early phase of the TETRA deployment the market of PSS mobile networks looked attractive (large and fast growing). Today there is a common understanding of the limitations of the market size of PSS communication equipment. This is the reason why the infra markets are dominated by only two suppliers (Cassidian, Motorola). The frequencies for WB and BB are still missing. The LTE may be developed first in the United States.

Cellular network equipment supplier

Interests	The next step in the PSS mobile communication, i.e. the BB data

	service may be implemented by LTE.
Alternatives	The future evolution of the PSS network has the two following steps: (1) how to implement high speed data needs and; (2) how to replace TETRA somewhere in the late 2020s. The first need will be fulfilled using (a) commercial networks, (b) building a dedicated WB (TEDS) or (c) BB (LTE) – or both WB and BB networks. The step 2 means the implementation of the PSS voice communication functionalities into a new specific technology, e.g. into LTE (Sundkvist, 2008).
Pros	New WB and BB needs are a new opportunity.
Cons	The volumes stay low comparing to the commercial cellular business.

Terminal manufacturers

Interests	The volumes of PSS mobile terminals have been low comparing to the cellular technology volumes. Three manufacturers (Motorola, Cassidian, Sepura) have a major part of TETRA terminal markets - the cellular mobile phone vendors have not been interested in PSS terminals. The situation would be different, if the BB solution is based on the commercial technology.
Alternatives	The TETRA terminal market is so small, that no major changes can be expected in the markets. TEDS is also a niche product. Most probably the TETRA terminal vendors would be only suppliers to that market. The volumes are smaller than the volume of TETRA terminals, because the usage of TEDS may be limited to the vehicle environment. If BB is used only for data communication, the terminals could be very close to the consumer market products.
Pros	The possibility to utilize cellular technology platforms may speed up the development of PSS terminals and develop the markets and the growth of the market.
Cons	The PSS terminal users expect the terminals to fulfil tougher environmental specifications, e.g. the dust and water protection to IEC529 IP54 (Sepura, 2010), than what is required in ordinary cellular

terminals. Also some other specific functionality may be required, like encryption, the emergency key, etc.

Application developers

Interests	The increased data transmission capacity makes possible wider selection of applications in the PSS networks and also the utilization of the applications developed for the commercial networks.
Alternatives	The TETRA network has low data transmission capacity (few kilobits/s), which limits the scope of the applications. The TEDS network supports data speeds of 50…200kbit/s, which is enough for almost all applications, except for video transmission and for web-browsing. The BB network would be optimum from the application developers' point of view.
Pros	The new WB and BB needs are a new opportunity for the application developers.
Cons	Applications should work is all data networks, in TEDS, in the dedicated BB network and in the commercial BB network as well as partially also in the TETRA network. The smooth roaming between the networks is also required.

4.4 Interviews

In the beginning of the scenario planning process (Fig. 3) the change forces are defined. The source of any such force is a stakeholder or an actor of the PSS value network. The interviews of the stakeholders are used to find the main forces which are affecting to the evolution of the Public Safety and Security networks.

The stakeholder analysis is a basis to define the right actors to interview. The interviews have been arranged face-to-face and the answers to each question are based on everyone's own experience and knowledge. The persons who were interviewed represent operators, authorities, emergency organizations and system suppliers. The titles and organizations of the interviewees as well as the day of the interview are listed in Appendix 1.

The key questions which the interviewee was asked to answer, are targeting to find the forces, which will have a role in the development of future emergency radio networks, like:

- what are the forces affecting to the future development of PSS mobile networks?
- which of these forces are biggest – please, score them (1…5)
- which of these forces are most uncertain - please, score the predictability (1…5)

The specific questions were done concerning on the forces in the area of politics, economic, society, technology, industry as well as end-users and functionality. Some more detailed questions were done to get a deeper understanding of future trends. Finally the interviewees were asked to clarify the services and applications which are essential in the PSS mobile networks: list and rank 5 new most important functionalities, which might be taken into use in the next 5 years. The complete list of interview questions is shown in Appendix 2. The interview results are presented in the following table (Table IV) the answers organized according to PEST (Political, Economic, Social, Technological) analysis. When the forces are defined, also the scores of them are justified at the same time. The score parameters describe the importance of the force comparing to other forces in the range of 1…5, and the predictability of the existence of the force. Each force is described in the next chapter.

4.5 Description of Forces

Political forces

1. Increase of terrorism and crime: terrorism and crime are continuously increasing in the world. This phenomenon will mean tougher requirements for PSS communication services.

2. Openness in activities of authorities: today the authorities are forced to work openly and if necessary to prove - based on the logs – the legitimacy of their activities. This requires better logger systems and possibilities to review the performance of the authorities.

3. Availability of additional spectrum: The availability of spectrum for PSS mobile networks is unclear (Donohue, 2010). The need is obvious and urgent.

TABLE IV

FORCES EFFECTING TO THE DEVELOPMENT OF PSS DATA NETWORK

Political forces		
1. Increase of terrorism and crime	5	2
2. Openness in activities of authorities	3	4
3. Availability of additional spectrum	5	1
Economic forces		
4. Budget financing of PSS networks	5	1
5. Development of mobile command and control	5	2
6. Instability of ownership of the commercial networks	4	3
7. Return on Investment (RoI) requirement	4	3
8. Operational costs	4	5
Social forces		
9. Internet generation is driving the use of Internet	3	5
10. Additional vulnerability of society	4	3
11. New emergency agencies	4	4
Technical forces		
12. The technology gap between PSS and 3G networks	5	5
13. The development of new PSS mobile technology	5	1
14. The development of TEDS solutions	5	3
15. Intelligent terminals, with storage capacity	3	3
16. Development of the compression technique	4	4
17. Diversity of networks and terminals	4	4
18. Tighter security requirements	5	1
19. Network traffic load control	3	2
20. Good communication tools of the criminals	4	4
21. Dynamic spectrum access and cognitive radios	5	1
22. Access to local memory storages	3	3
23. Role of memory storage sensors (rfid)	3	1
Industry/Operator forces		
24. The PSS business case of commercial operators	4	4
25. Path dependence of existing PSS networks	4	4
26. Poor reliability of commercial networks	5	4
27. Situation awareness sets new requirements	5	2
28. Fast expansion of 3G networks	4	4
End-user/functionality forces		
29. Expectations based on 3G services/functionalities	5	4
30. Increase of crucial data communication	5	4
31. Operational pressure for new applications	5	1
32. Indoor coverage requirements	3	3

First column = Name of the force affecting to the development of PSS data network
Second column = Importance of the force
Third column = Predictability of the force

Economic forces

4. Budget financing of PSS networks: most countries have challenges to keep the government budget in balance.

5. Development of mobile command and control: the improvement of the operational efficiency will move the management of the groups more and more to the field. The field management has to have the same access to the situation awareness information what the personnel in the command and control centre has – the effective communication link is needed. This functionality may be “a killer application”, which drives the roll-out of WB or BB data networks for PSS use (Hong Kong Police, 2010), (Suomen Erillisverkot, 2010b).

6. Instability of ownership of the commercial networks: commercial cellular networks could be utilized as mobile networks for the PSS organizations, however the ownership of the network is a security issue – the ownership can change quickly and stay unclear – and this way is a risk (Liikenne- ja viestintäministeriö, 2009b).

7. Return on Investment (RoI) requirement: governments are setting clear targets that also the investments, targeting the wellbeing of the population, have to have good costs per benefits ratio.

8. Operational costs: the expected operating costs of the PSS mobile network have a major impact when deciding the future solutions of the PSS mobile system.

Social forces

9. Internet generation is driving the use of Internet: the young people drive the development of the communication – which is based on the Internet.

10. Additional vulnerability of society: the population is more vulnerable than earlier – this has increased expectations from the authorities.

11. New emergency agencies: the telecommunication, the power and water supply, the public transport, etc. have become critical to society. This means, that the number of organizations, which can be seen as emergency agencies, increases.

Technology forces

12. The technology gap between PSS and 3G networks: the performance of 3G technology is superior in many areas compared to the capability of the PSS mobile technology. Also the economies of scale are giving a big advantage to 3G.

13. The development of new PSS mobile technology: WiMAX has lost the advantages which it had when it was first launched (*Viestintävirasto*, 2009). LTE has a strong position in the United States to be a future BB data technology for PSS agencies (Wyllie, 2010). If LTE technology is quickly taken into use for data communication in US PSS networks, it may have a strong impact on the future technology choices in Europe. The development of a new technology is strongly linked to the spectrum allocation decisions.

14. The development of TEDS solutions: the updating of the existing TETRA network with the TEDS technology is a way to supply the wideband service (50…200kbit/s) for the emergency agencies, but the availability of spectrum and the willingness of the governments to finance the updates are unclear. The low volumes of terminals – if the TEDS network covers only rural areas – means that only the vehicle terminals are developed.

15. Intelligent terminals with storage capacity: the intelligence and storage capacity of the cellular terminals increases all the time – and people are used to it. This may cause expectations to the users of professional terminals, but it will also give new opportunities to process the information and run applications in the terminals.

16. Development of the compression technique: the development of the compression technique will lower the data speed requirements.

17. Diversity of networks and terminals: the future will not be composed of a single wireless network or technology (Lehr, 2009a), e.g. there are many types of networks offering a variety of geographical ranges and range of capabilities (Ittner, 2006).

18. Tighter security requirements: the communication security is lost, if there are eavesdropping, radio signal disturbing or an attempt to modify the content of the signal – the existing PSS communication systems have good encryption algorithms, but new threats may appear.

19. Network traffic load control: the traffic load of the emergency network can be huge during emergency cases. Better tools are needed to monitor and control the traffic and users' access during the overload of the network.

20. Good communication tools of the criminals: the smart phones with the always-on Internet connections have superior communication capability compared to the terminals what the emergency agencies have today.

21. Dynamic spectrum access and cognitive radios: the requirements to utilize spectrum more effectively can be fulfilled by using the dynamic spectrum and cognitive radio technologies. It will be challenging to implement the mechanism which controls the access priorities.
22. Access to local memory storages: the databases of the authorities have quite stable content – it can be downloaded in the central station and if necessary download modifications using the narrowband connection. These types of applications do not need BB data links.
23. Role of memory storage sensors (RFID): the local databases, which consist of any information of the local environment, can remove a major part of the communication needs in the mobile networks (Teliasonera, 2009) and instead the main part of the communication could be based on the local WLAN (or similar) communication links.

Industry/Operator forces
24. The PSS business case of commercial operators (NPIA, 2009)*:* the public safety and security communication business case for the commercial operators is challenging, because the PSS communication service will require longer battery back-up times than what is specified for the cellular networks. The repairing times also should be shorter and overall the availability requirements are tougher in the PSS case. The listed issues could mean remarkable additional costs to the commercial operator. The operator might try to sort out the issues by agreeing the high remedy payments, which in any case would be lower than all needed additional operation and investment costs.
25. Path dependence of existing PSS networks (Liebowitz & Margolis, 2001): The existing PSS communication networks with their spectrum reservations have a strong path dependence influence on any plan of replacing them.
26. Poor reliability of commercial networks: the tough competition in the communication business has lowered the quality of the commercial telecom operator services (*Suomen Erillisverkot Oy*, 2010a). *Liikenne- ja viestintäministeriö* (2009b) has emphasized the necessity of the sufficient battery back-ups in the base station sites. In case of emergency situations the commercial networks will become blocked. The usage of priorities in this case has several drawbacks (section 2.5).
27. Situation awareness sets new requirements: the utilization of video surveillance data improves the situation awareness in emergency cases. The usage of video means

additional capacity needs in the mobile networks. The mobile command and control functionality requires also situation awareness information.

End-user/functionality forces

28. Fast expansion of 3G networks: The coverage and the capacity of the 3G networks grow very fast together with the usage of the 3G services.

29. Expectations based on 3G services/functionalities: the young generation of the emergency personnel is used to 3G services (later LTE services) and to the sophisticated type of user interface – they will expect as good in their work.

30. Increase of crucial data communication: the speech (group communication) has been far more the most important service in PSS mobile networks, but today also data transfer is crucial (location services, data queries, messaging, etc.).

31. Operational pressure for new applications (video streaming, "office applications", patient information): video streaming is seen as an important element to improve the situation awareness information during critical field operations; email and web-browsing need at least the WB service.

32. Indoor coverage requirements: the emergency agencies expect as good indoor coverage - when using their emergency mobile terminals - as they experience with the GSM networks. This is something that has an impact to the selection of future technologies.

4.6 Trends and uncertainties

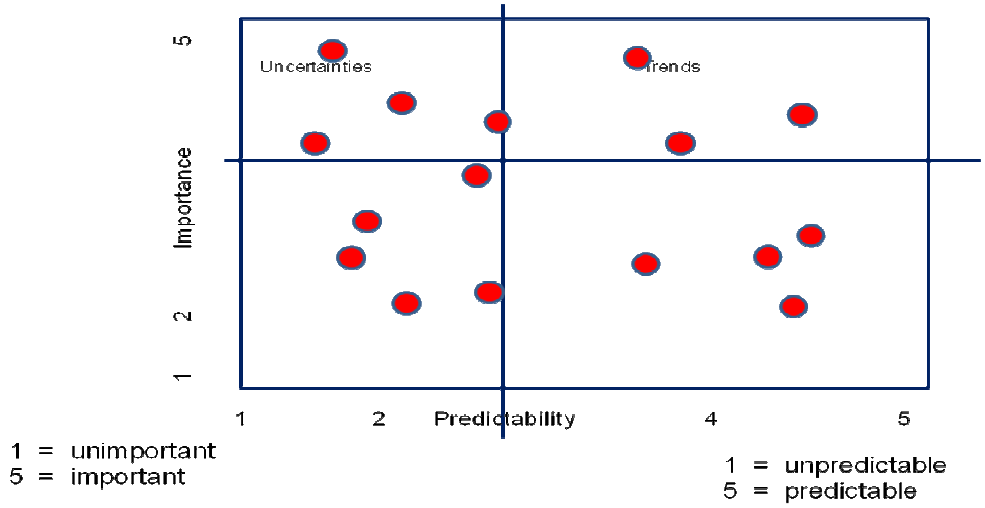

Fig. 7. Defining trends and uncertainties

The definition of trends and uncertainties is based on the scoring, what is defined for the forces. The force is named as a trend if its importance is 5 and its predictability at least 3 or if its importance is 4 and its predictability at least 4. The forces, whose importance is 5 and the predictability less than 3 are named as uncertainties (Schoemaker, 2000). The principle is presented in Fig. 7. The main uncertainties are listed in Table V – in order of priority, the most important being listed first.

TABLE V
THE MAIN UNCERTAINTIES

3. Availability of additional spectrum	5	1
4. Budget financing of PSS networks	5	1
13. The development of new PSS mobile technology	5	1
18. Tighter security requirements	5	1
31. Operational pressure for new applications	5	1
21. Dynamic spectrum access and cognitive radios	5	1
1. Increase of terrorism and crime	5	2
5. Development of mobile command and control	5	2
27. Situation awareness sets new requirements	5	2

First column = Name of the force affecting to the development of PSS data network
Second column = Importance of the force
Third column = Predictability of the force

The main trends are – in order, the most important first - listed in Table VI.

TABLE VI
THE MAIN TRENDS

12. The technology gap between PSS and 3G networks	5	5
26. Poor reliability of commercial networks	5	4
28. Expectations based on 3G services/functionalities	5	4
30. Increase of crucial data communication	5	4
14. The development of TEDS solutions	5	3
8. Operational costs	4	5
11. New emergency agencies	4	4
16. Development of the compression technique	4	4
17. Diversity of networks and terminals	4	4
20. Good communication tools of the criminals	4	4
24. The PSS business case of commercial operators	4	4
25. Path dependence of existing PSS networks	4	4
28. Fast expansion of 3G networks	4	4

First column = Name of the force affecting to the development of PSS data network
Second column = Importance of the force
Third column = Predictability of the force

4.7 Correlation between Uncertainties

The correlations between the main uncertainties have been defined and presented in Fig. 8, i.e. the left most column names the uncertainty whose correlation has been defined to other uncertainties (named on vertical lines). Using the results of the correlation matrix (Fig. 8), the causal loop diagram (Sterman, 2000), is drawn (Fig. 9), to understand better the causal influences between the main uncertainties.

	3	4	13	18	31	21	1	5	27
3. Availability of additional spectrum			+++			+++			
4. Budget financing of PSS networks			+++						
13. The development of new PSS mobile technology						+++	+++		
18. Tighter security requirements	+++	+++	+++		+++		+++		+++
31. Operational pressure for new applications	+++	+++	+++						
21. Dynamic spectrum access and cognitive radios	+++		+++						
1. Increase of crime and terrorism	+++	+++	+++	+++	+++				+++
5. Development of mobile command and control			+++		+++				+++
27. Situation awareness sets new requirements					+++			+++	

Fig. 8. Correlation between uncertainties (+++ = strong correlation)

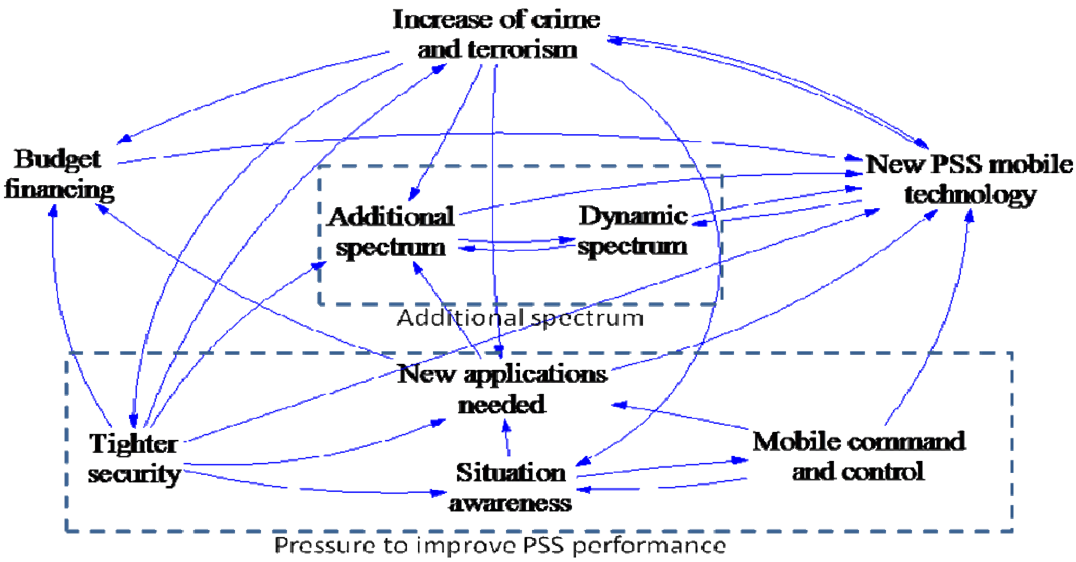

Fig. 9. Causal diagram analysis of the key uncertainties

The following conclusions can be made based on the correlation matrix and on the causal diagram:

1. The uncertainties (Fig. 9) “Pressure to improve PSS performance” (i.e. “5.Mobile command and control”, “18.Tighter security”, “27.Situation awareness” and “31.New applications needed”) are strongly affecting the other uncertainties.
2. The uncertainties (Fig. 9), “3.Additional spectrum” as well as “21.Dynamic spectrum” can be seen to belong to the same class of uncertainties – both influence the usage of the spectrum – and will have a crucial influence on the future evolution of the PSS mobile solutions. “21.Dynamic spectrum” is a strong force if there will be a lack of additional spectrum. However, if new spectrum can be achieved those techniques are not crucial. Because the development of the both uncertainties - “3.Additional spectrum” and “21.Dynamic spectrum” – is tightly connected with the possible new spectrum allocation, therefore, the both uncertainties are called using a common term ”Additional spectrum” (ref. Fig. 9).
3. “13.New PSS mobile technology” force is a force, which is strongly affected by other forces.
4. “4.Budget financing” is also a force, which is strongly affected by other forces.
5. “1.Increase of crime and terrorism” is a strong force, affecting almost all other forces, but it could be seen to affect mainly through “Pressure to improve PSS performance” forces.

Based on the above analysis the forces “Additional spectrum” and “Pressure to improve PSS performance” are selected as key uncertainties when defining future scenarios.

Chapter 5

Constructing Four Scenarios

Two main uncertainties have been selected for developing four scenarios (Schoemaker et. al., 2000). The selection of the two main uncertainties is done by choosing two of those uncertainties, which according to the interviews are anyway the most important and uncertain ones, and based on the correlations matrix and causal diagrams are as much as possible mutually independent and influential. The selection of the uncertainties is based on the results in section 4.7, and represented in Fig. 10.

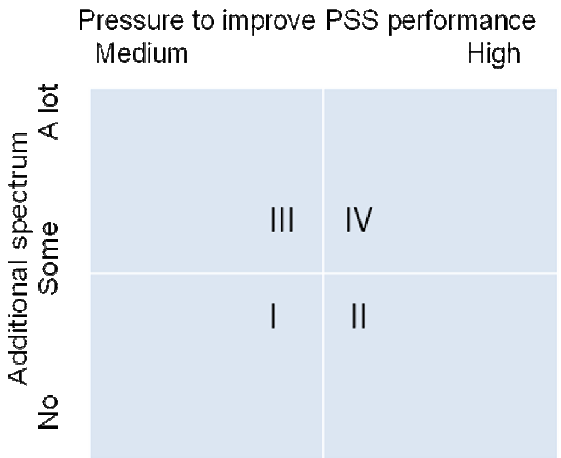

Fig. 10. Two main uncertainties form 2 x 2 scenarios matrix.

In Fig. 10 the vertical axis “Additional spectrum” is representing spectrum related uncertainties and the horizontal axis “Pressure to improve PSS performance” is representing the pressure to take new applications into use.

Each of the four quarters represents a specific scenario.

The defined scenarios are “Performance through data processing”, “Commercial operators active to provide communication media”, “PSS operators expand their scope” and “Communication media enables advanced PSS services”. Figure 11 represents the scenarios.

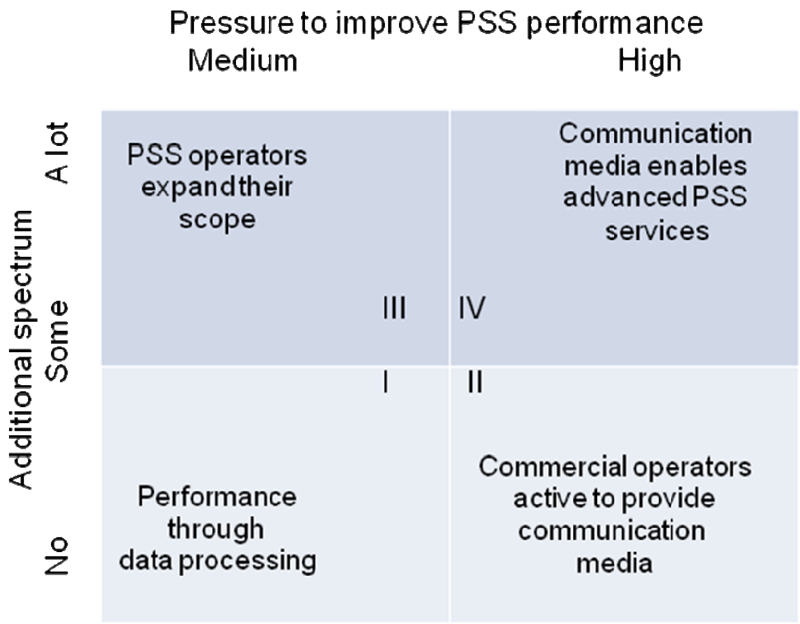

Fig. 11. Four scenarios in quarters I, II, III and IV

Each of four scenarios is described in the following. The scenario description includes all forces (trends or uncertainties) which are scored as the most important, i.e. the top 13 trends and 9 uncertainties.

5.1 Performance through Data Processing

Scenario I is very much the existing solution, there is no additional spectrum available and there is medium pressure to take new applications into use to improve the performance. The medium performance improvements can be made (1): by utilizing commercial networks for the non-critical communication; (2) by taking into use the TEDS technology, if the existing frequency band allows that and (3); by improving the usage of the communication channels. The latter can be done with better compression technology, by packaging data more efficiently and by improving the communication of the applications so that the transmitted data volumes are optimized.

Description of trends and uncertainties in the scenario "Performance through data processing"

Availability of additional spectrum: no additional spectrum for PSS communication usage allocated.

Budget financing: government's financing is minor, because only medium pressure for new PSS supporting applications.

The development of new PSS mobile technology: PMR industry is offering 50 kHz TEDS solutions for updating existing networks.

Tighter security requirements: authorities do not see any growth in terrorism or in crimes – so new threats are not indentified.

Operational pressure for new applications: medium pressure, few new applications are interested, mobile video has no use.

Dynamic spectrum access and cognitive radios: no new spectrum is allocated, but no urgent needs are seen. The development of dynamic spectrum and cognitive radio technology is not boosting.

Increase of terrorism and crime: authorities do not see any growth in terrorism or in crimes.

Development of mobile command and control: mobile command and control will be based on the narrow band communication; the functionality of the mobile command and control stays low.

Situation awareness sets new requirements: video is not seen as a crucial element to improve the situation awareness.

Technology gap between 3G and PSS networks: there is a real gap. The increased utilization of commercial cellular networks is used to decrease the gap. When the LTE networks are taken into use the gap becomes enormous.

Poor reliability of commercial networks: authorities try to limit the risks by making the service agreement with all cellular operators.

Expectations based on 3G services/functionalities: expectations of users will lead to the behaviour where critical data is moving partly to commercial cellular networks because it offers better usability.

Increase of crucial data communication: data will be split to critical and non-critical, the amount of crucial data cannot be increased.

Development of TEDS solutions: 50 kHz channel TEDS is widely utilized. The lack of portable TEDS terminals limits its use to the vehicle environment.

Operational costs: this scenario does not increase the operational costs remarkably.

New emergency agencies: new agencies will use commercial cellular networks for their communication – in this scenario there is no addition in the PSS network capacity.

Development of the compression technique: the better compression technology and the store and forward capabilities of the surveillance cameras with local WLAN connections improve the TEDS (50 kHz channel) based network performance.

Diversity of networks and terminals: together with the TEDS network the commercial 3G services are taken into use for non-critical communication like for reporting, office routines, etc.

Good communication tools of the criminals: the benefit the authorities have had for decades in telecommunications has been lost. The missing reliable, secured high speed data mobile communication will have impacts on the performance of the authorities.

Business case of commercial operators: the usage of commercial networks only for non-critical communication is according to the business capabilities of the operators.

Path dependence of TETRA technology: the made decision to utilize TEDS technology is well suited to the path dependence.

Fast expansion of 3G networks: the coverage of the 3G network is improving quickly and the good access and good performance of 3G networks may lead to the situation where a part of critical communication will be moved to the 3G network. However, in the case of emergency the availability of the network is not guaranteed.

Concluding of the scenario "Performance through data processing"

Phenomena promoting this scenario: The economic turmoil may be the strongest phenomenon promoting this scenario, i.e. it is difficult to get budget financing for any major PSS mobile network improvements. And at the same time there is no confidence on the availability of commercial networks, or the commercial operators do not really want to carry the risk of the availability.

Phenomena preventing this scenario: Additional threat of crime and terrorism. The quick and fast roll-out of LTE technology in commercial networks will create a lot of expectations of the functionality of the mobile networks.

5.2 Commercial Operators Active to Provide Communication Media

Scenario II is the case, where there is strong pressure to take new applications into the use; the financing can be arranged, but the additional spectrum is missing. In this case the only solution is to utilize the existing frequencies in an optimal way. This is done: (1) by building as much TEDS capacity as possible within the existing frequencies and; (2) by using commercial BB networks for non-critical high speed data transportation without sacrificing the availability and security.

Description of trends and uncertainties in the scenario "Commercial operators active to provide communication media"

Availability of additional spectrum: no additional spectrum for PSS communication usage allocated.

Budget financing: the governments finance the network performance improvement investments.

The development of PSS technology: increased application needs and the lack of frequencies will boost the PSS industry to focus on the saving of the spectrum.

Tighter security requirements: the increased use of the commercial networks means more detailed work instructions to emergency agencies.

Operational pressure for new applications: Video streams are seen as important tools for improving the situation awareness capability.

Dynamic spectrum access and cognitive radios: the lack of frequencies for PSS communication will boost the research of these technologies.

Increase of terrorism and crime: this scenario expects that there is no increase.

Development of mobile command and control: solution is implemented based on TEDS communication media.

Situation awareness sets new requirements: the BB service in commercial 3G networks offers an efficient media for situation awareness data. However, this communication channel may not be available all the time.

Technology gap between 3G and PMR: TEDS with the 50kHz channel bandwidth and the utilization of a commercial 3G network help to remove the gap. However, when the LTE networks are taken into use, it may cause the critical communication to partly move into commercial networks.

Poor reliability of commercial networks: this is an issue and that's why the critical data is transmitted via the TEDS network. The acceptable power failure recovery solutions and short repair-times are expensive to supply in commercial 3G networks, where the number of base stations is large.

Expectations based on 3G services/functionalities: the users' expectations will lead to the behaviour where critical data is moving partly to commercial cellular networks because it offers better usability.

Increase of crucial data communication: the amount of crucial data has increased. TEDS has become as essential part of communication media as TETRA has been.

Development of TEDS solutions: TEDS is developed using the 50 kHz channel bandwidths.

Operational costs: Operational costs are at the same level concerning on the TETRA and TEDS networks. The cost structure of the commercial operators may start to increase, because of the new requirements of the availability.

New emergency agencies: the new emergency agencies are not taken to the customers of the PSS network, due to the lack of communication capacity. The new agencies may accept more and more commercial networks if they are quite widely used by the PSS organizations.

Development of the compression technique: the better compression technology as well as the store and forward capabilities of the surveillance cameras with local WLAN connections improve significantly the TEDS based network performance.

Diversity of networks and terminals: together with the TEDS network the commercial 3G services are taking into use for non-critical communication like for reporting, office routines, etc. WLAN connections are used locally to download database type of information. Applications utilize any network that is available.

Good communication tools of the criminals: the benefit that the authorities have had decades in telecommunications has been lost. The missing reliable, secured high speed data mobile communication will have impacts on the performance of the authorities.
The scenario where PSS communication is implemented using widely commercial 3G networks offers similar communication tools for criminals and officials. The protection of the commercial networks of the disturbances will be an issue.
Business case of commercial operators: the usage of commercial networks only for non-critical communication is in balance with the business capabilities of the operators.
Path dependence of TETRA technology: the made decision to develop TEDS solution is well suited to the path dependence.
Fast expansion of 3G networks: the expansion of 3G and LTE networks improve their possibilities to be utilized by the emergency agencies. However, in the case of an emergency the availability of the networks is not guaranteed.

Concluding of the scenario "Commercial operators active to provide communication media"
Phenomena promoting this scenario: the United States has started to build PSS LTE network based on the public-private partnership concept or the fast expansion of the commercial 3G/LTE networks with the availability improvements.
Phenomena preventing this scenario: The poor availability of commercial networks. The cellular subscribers are suspicious of the network's availability in emergency situations and change the operator.

5.3 PSS Operators Expand their Scope

Scenario III is a case, where the PSS operator expands their scope to the fixed wireless BB service offering in rural areas by utilizing the new allocated frequencies. The fixed wireless service in rural areas causes no risk to the network availability. There is only minor operational pressure to take new applications into use. The TEDS network is built in the area which stays between suburban and rural areas. As a conclusion the dedicated BB network is built into the urban and suburban areas as well as into the low populated rural areas. The frequencies will be utilized reasonably well, the fixed wireless business supports the investment costs in rural areas and the “commercial” customers are in the business segment, which is not interested by the commercial operators.

Description of trends and uncertainties in the scenario “PSS operators expand their scope”

Availability of additional spectrum: additional spectrum for PSS usage is allocated for PSS BB services in the area of 380…470 MHz.

Budget financing: the governments finance the new network investments. In rural areas, part of the investment can be seen as a support for “wideband to every home” objectives.

The development of PSS technology: the BB solution utilizing the new spectrum is based on commercial cellular technology – and suppliers of that technology are the vendors of the commercial mobile networks. The volumes of TEDS stay low – this scenario is a challenge to the PSS communication industry.

Tighter security requirements: no specific new requirements

Operational pressure for new applications: the pressure is low, some new applications are seen as important.

Dynamic spectrum access and cognitive radios: the need for new spectrum has been fulfilled – the dynamic spectrum access is a new technology, not mature enough for PSS applications.

Increase of terrorism and crime: the reason for the allocation of new spectrum is the threat of terrorism and crime.

Development of mobile command and control: the new spectrum allows the BB based implementation of the high quality mobile command and control application.

Situation awareness sets new requirements: the BB service utilizing the new spectrum offers an efficient media for situation awareness data.

Technology gap between 3G and PMR: Not a relevant issue after new spectrum.

Poor reliability of commercial networks: this is not an issue.

Expectations based on 3G services/functionalities: these expectations can be fulfilled.

Increase of crucial data communication: the amount of crucial data has increased – the needs can be fulfilled.

Development of TEDS solutions: TEDS is developed, using the 50 kHz channel bandwidths. However, because the BB network is built also in rural area, the area where WB/TEDS is utilized stays small.

Operational costs: Operational costs are remarkable higher than in *Scenarios I and II*. The BB network in rural areas may be challenging from the business point of view, the number of users remains low as well as the data volumes per subscriber.

New emergency agencies: new emergency agencies are allowed to use the PSS data communication network because there is enough capacity; they also improve the business case.

Development of the compression technique: the scenario is not pushing better compression technology.

Diversity of networks and terminals: all networks, TETRA, TEDS and the BB network are used. Also WLAN connections are used locally to download database type of information. Applications have to be able to utilize any network that is available.

Good communication tools of the criminals: The reliable, secured high speed data PSS mobile communication – which is available within the new frequency band - will give authorities at least as good communication tools which the criminals have.

Business case of commercial operators: not relevant. The operation of the PSS operators in rural areas may be a competition law issue.

Path dependence of TETRA technology: the made decision to base the data communication on TEDS and BB fits with the path dependence.

Fast expansion of 3G networks: in this scenario not a relevant issue.

Concluding of the scenario “PSS operators expand their scope”

Phenomena promoting this scenario: The allocated new frequencies are in the area of 350…470 MHz. The scenario is an intermediate step on the roadmap towards the quarter IV. The commercial networks are unable to fulfil the availability requirements.

Phenomena preventing this scenario: The implementation of the fixed wireless BB mobile network in rural areas may be a challenge from a business perspective – and the commercial operators may be against the spectrum allocation. The allocation of new spectrum, but with no high pressure of new applications, in an unlikely combination.

5.4 Communication Media Enables Advanced PSS Services

In *Scenario IV* a strong pressure to take new applications into use exists and the additional spectrum has been allocated. Because of the optimization of the investment the high availability WB network is built covering the whole country excluding the urban and the suburban areas. The dedicated BB network, which can be based on the LTE technology covers the urban and the suburban areas.

Description of trends and uncertainties in the scenario "Communication media enables advanced PSS services"

Availability of spectrum: a part of the digital dividend spectrum is allocated for PSS usage, 2x3 MHz for TETRA and 2x3 MHz for WB data – both in the 380…470 MHz area. Additionally 2 x 10 MHz in the 700 MHz area has been allocated for BB (Wählen, 2010).

Budget financing: the governments have increased the financing of the PSS sector because of the tough operational requirements and the threat of crime and terrorism. The additional financing covers the investment costs of the new BB network in urban and suburban areas.

The development of new PSS mobile technology: the new spectrum allocations will increase the investments in PSS communication and it will boost the overall development of PSS technology. However, the BB data network is based on commercial mobile technology and is not supplied by PSS communication vendor. The PSS BB solutions in the United States, i.e. the LTE networks, have a major impact on the technology choices in Europe.

Tighter security requirements: the own, dedicated network covers these requirements.

Operational pressure for new applications: mobile command and control is the "killer" application of the new BB mobile network. Video streams are also seen important tools for improving the situation awareness capability.

Dynamic spectrum access and cognitive radios: because the needs of spectrum are fulfilled, the utilization of these technologies is not crucial any more.

Increase of terrorism and crime: the threat of terrorism and crime is noticed. The allocation of spectrum and the development of new applications will deny the threat.

Development of mobile command and control: the built WB/BB data network supports this application.

Situation awareness sets new requirements: the secured BB network is a good platform to develop the situation awareness concept.

Technology gap between 3G and TETRA: not a relevant issue anymore.

Poor reliability of commercial networks: not relevant because almost all data is transferred in the own network,

Expectations based on 3G services/functionalities: not an issue in this scenario.

Increase of crucial data communication: even though the crucial data communication increases, there is enough capacity to cover needs.

Development of TEDS solutions: TEDS is developed, typically using the 100 kHz channel bandwidths – TEDS is mainly utilized in rural areas where the coverage of BB is missing.

Operational costs: the operational costs are higher than earlier, but the increased need for security makes costs acceptable.

New emergency agencies: increased vulnerability of society will increase the number of emergency agencies; new emergency agencies, like power utilities, public transport and security companies use the PSS network.

Development of the compression technique: the available capacity fulfils all needs – no urgent need.

Diversity of networks and terminals: the PSS mobile communication network will be based on many technologies and networks, dedicated TETRA, TEDS, WLAN and 3G/LTE/700MHz as well as commercial 2G/3G network.

Good communication tools of the criminals: the criminals and authorities are using similar technologies – however, the PSS network offers better availability.

Business case of commercial operators: the usage of commercial networks only for non-critical communications is in balance with the business capabilities of the operators.

Path dependence of TETRA technology: TETRA technology will be used for voice and low speed data (e.g. GPRS position signalling) transportation. TEDS will use the same base stations and sites – so the benefits of TETRA technology will be utilized.

Fast expansion of 3G networks: The dedicated BB mobile network, even in the limited area of the country, removes the main needs to utilize commercial networks. However, the applications are easier to develop to work in both networks.

Concluding of the scenario "Communication media enables advanced PSS services"

Phenomena promoting this scenario: Threat of increasing terrorism and crime – so additional spectrum will be allocated. The 700 Mhz LTE system development in the United States.

Phenomena preventing this scenario: The commercial operators manage to ensure the PSS level availability in their cellular network. Budget financing problems.

5.5 Conclusion of Scenarios

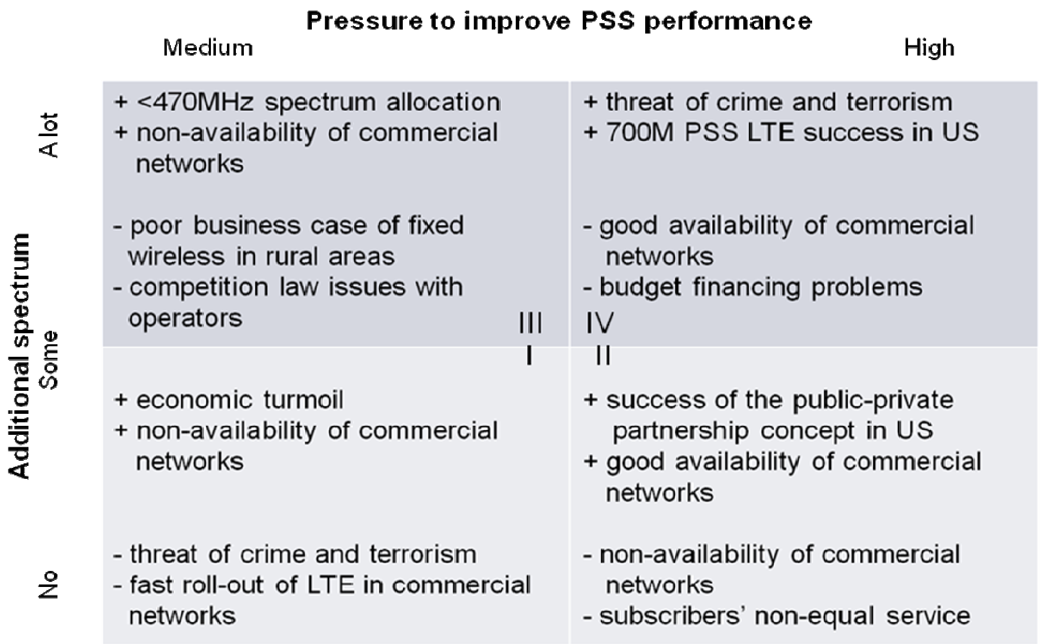

Fig. 12. The issues to promote (+) and to prevent (-) a scenario happening

Fig. 12 represents the conditions when the defined scenarios most probably will happen. Except the main forces (Additional spectrum, Pressure to improve PSS performance), the two promoting and the two preventing forces are shown within each scenario. The availability of the commercial networks as well as the development and the roll-out of the 700MHz LTE network in the United States have significant impact on the scenarios.

Chapter 6

Strategic Implications

After the scenarios have been developed, the analyzing of the scenarios is done using Porter's (1985) approach, where five alternative strategies are developed for the firm involved with the business. According to the Porter (1985), the five possible strategies are: firstly a strategy, where you bet on the most probable scenario, secondly you bet on the best scenario, or thirdly you choose a strategy, which is satisfactory under all scenarios (this alternative is called as "Hedge"). The fourth alternative is a strategy which preserves flexibility until the final scenario is known, known as "Preserve flexibility". The fifth one is a strategy, where you intend to influence as much as possible the scenario you feel to be favourable to you – this is called "Influence".

In this study the most appropriate stakeholder, for whom the strategy is first defined, is the PSS network operator (it could also be an authority, which in this case is seen as an owner of the PSS operator).

As we can see in Table III, the time when the digital PSS networks are taken into operational use varies country by country from 2001 until 2010. This means that also the timetables to invest in new PSS mobile network technologies will vary significantly in various countries. The timing shown in the five strategy variants is valid to the countries which have opened the digital PSS mobile services within the first years of the 2000s.

After the strategy alternatives are reviewed with the main stakeholder, the PSS network operator, the compact reviews follow, how the defined five strategies would work with the other four stakeholders:

- Commercial mobile network operator
- PSS mobile technology supplier
- Commercial mobile technology supplier
- Application supplier.

6.1 PSS Network Operator

6.1.1 Bet on the Most Probable Scenario

The *Most probable scenario* is a scenario (Fig. 13), which seems to be an obvious choice based on the common knowledge of the business environment (Porter, 1985). When referring to the alternatives given by the scenario planning, and taking into account also the time span, the conclusion is the following: there is pressure to take new applications into use, e.g. the mobile command and control. The new applications

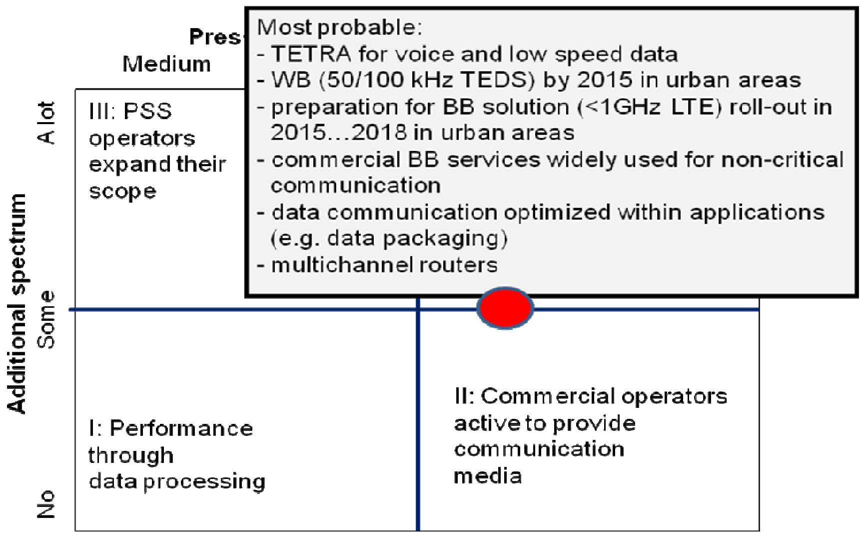

Fig. 13. Bet on the Most probable scenario strategy

require more data link capacity - and most probably at least some spectrum will finally be allocated for PSS communication usage. However, the allocation of new spectrum is a slow process, and besides the allocation, the time is needed for standardization, product specification, product development and network implementation. Because of that, in the first step the additional capacity requirements have to be fulfilled with the existing frequency bands, utilizing spectrum more efficiently and using commercial networks where possible. In practise this means better usage of the narrowband data transmission, by building 50kHz channel TEDS networks where free frequencies exists – first in urban and suburban areas – and to transfer non-critical communication into the commercial networks. The multichannel routers in the vehicles make possible running same applications over different networks. The work for starting the roll-out of the dedicated BB network (LTE < 1GHz) in 2015 is a part of this strategy.

6.1.2 Bet on the Best Scenario

The *Best scenario* is a scenario which is the most favourable to the PSS operator stakeholder in longer term taking into account its resources, competences and the starting point (Porter, 1985). The *Best scenario* to the PSS operator is (Fig. 14): the additional spectrum is allocated for the operator free of charge and the operational pressure for new applications stays in balance with the capability of the investments for

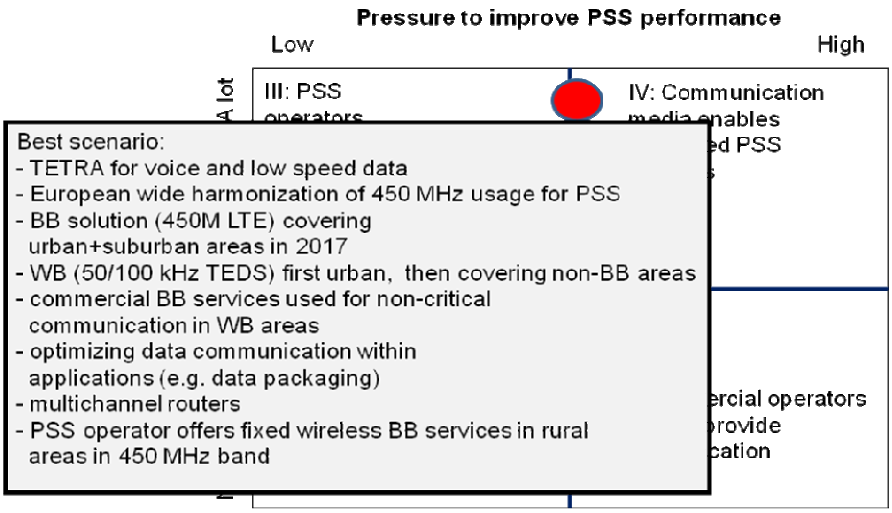

Fig. 14. Bet on Best scenario strategy

the new network. The additional data capacity will be built first in key urban areas based on the WB/TEDS technology and on the utilization of the existing base station infra. With the enhanced data compression technology and with the additional spectrum allocation for the WB network the selected solution can carry the present data communication needs, while at the same time the non-critical data communication is transferred to cellular networks. The BB network will start to be built in the 450 MHz range in 2015, so that the network covers the main part of the country in 2017. The PSS operator will also offer fixed wireless BB services in rural areas in the 450M frequency band. After the BB network is rolled out, the WB network role is to cover only those rural areas where the fixed wireless coverage does not exist.

6.1.3 Hedge

Hedge means that you choose a strategy, which makes you ready for any scenario alternatives and gives reasonable business results within all scenarios (Porter, 1985). Following this principle the defined strategy works with any of the scenarios QI, QII, QIII or QIV. However, the Hedge strategy gives often a result which is not optimal to any single scenario.

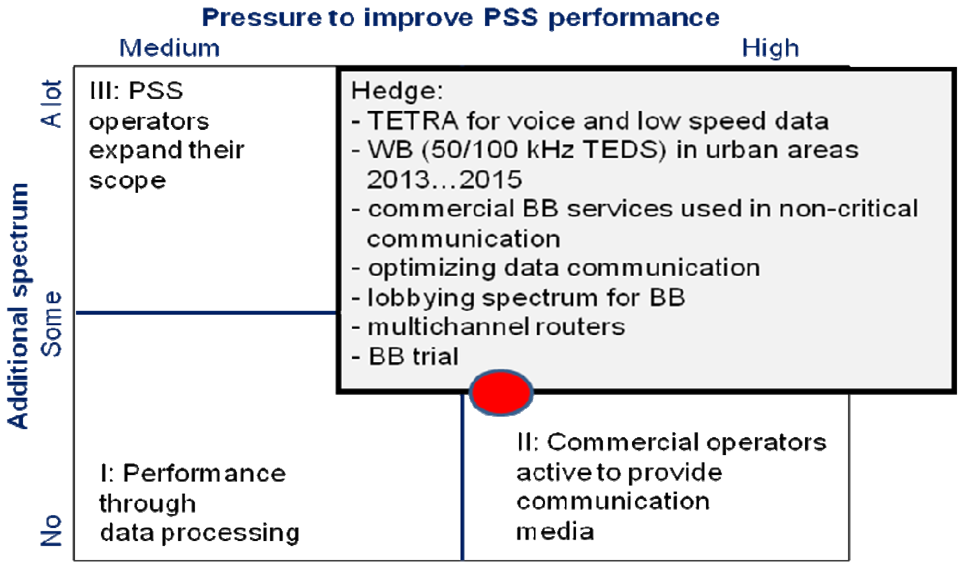

Fig. 15. Hedge strategy

Hedge in this case means a strategy, which (Fig. 15):

- utilizes the present TETRA network infra as much as possible

- some 50kHz TEDS networks will be built in cities to get experience of the technology
- data communication capabilities are improved by the compression techniques and by minimizing the volume of data transport in applications
- all non-critical data communication is transferred to cellular networks
- lobbying the allocation of the new frequency bands
- multichannel routers are taken into use to make roaming possible in all data networks
- BB trials will be done.

6.1.4 Preserve Flexibility

Preserve flexibility means that the strategy is flexible until it can be seen what the final scenario will be (Porter, 1985). The Preserve flexibility alternative strategy often gives results which are not optimal to any scenario. The Preserve flexibility option in this case means a strategy, which (Fig. 16):

- utilizes the present TETRA network infra as much as possible
- transfers all non-critical data communication to cellular networks
- lobbies the allocation of the new frequency bands.

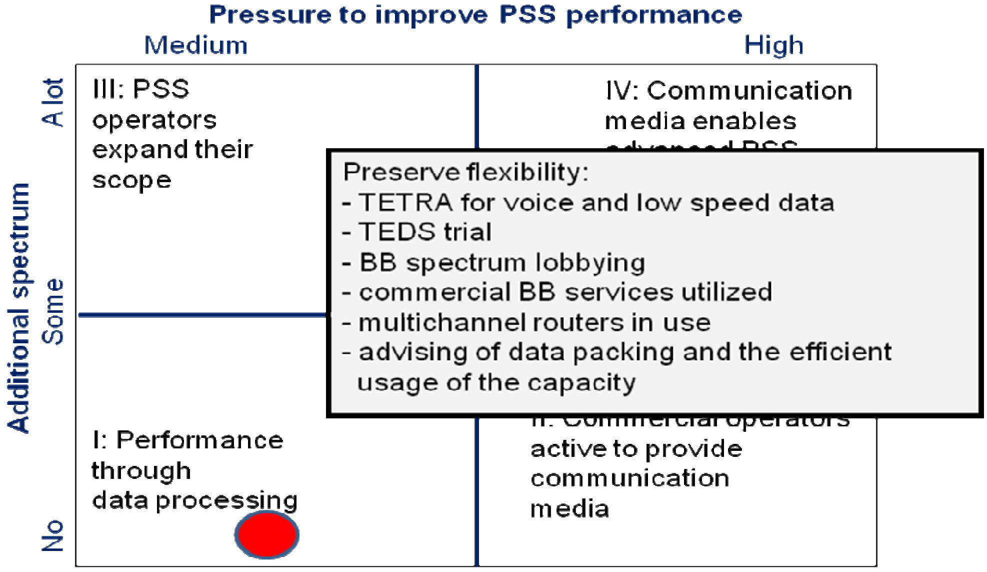

Fig. 16. Preserve flexibility strategy

6.1.5 Influence

In the *Influence* alternative (Fig. 17), the company uses its resources to push the scenario which seems to be favourable to the company (Porter, 1985). "The firm seeks to raise the odds that a scenario will occur for which it has a competitive advantage. Doing so requires that a firm try to influence the causal factors behind the scenario variables" says Porter (1985) of the Influence strategy. The desired scenario is (according to section 6.1.2) that the additional spectrum is allocated for the operator free of charge, the operational pressure for new applications stays in balance with the capability of new network investments as well as the data compression and the better utilization of data capacity are developed so that the needs of higher data speeds can be delayed at least slightly and the utilization of the existing network investment can be continued. The competitive advantages supporting this scenario are the existence of the present TETRA network, its narrowband data capacity and its base station sites. According to the definition, these advantages should be utilized in the desired scenario. This happens by influencing those uncertainties, and their causal factors, which are the key forces for the hoped scenario to happen.

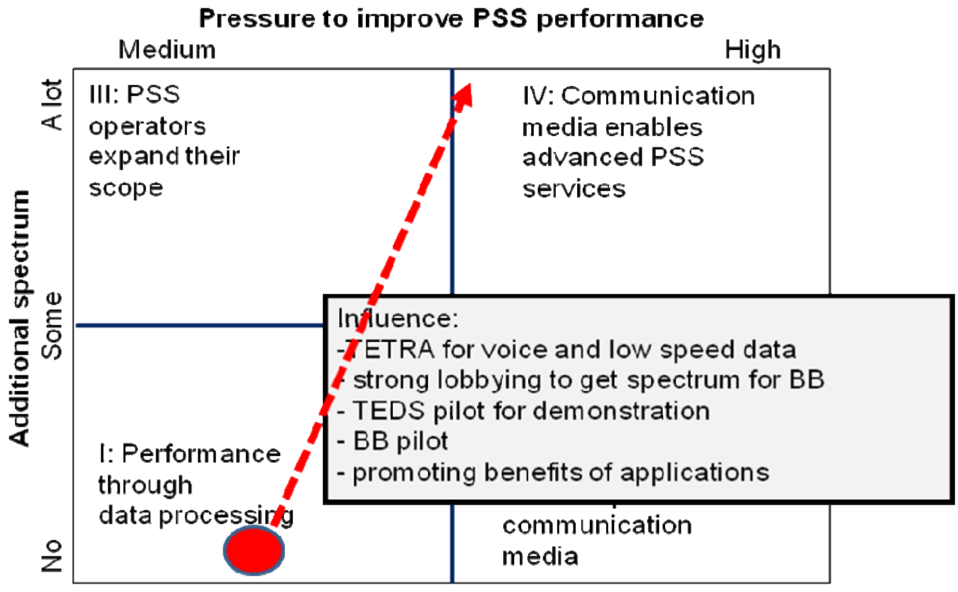

Fig. 17. Influence strategy

The *Influence* strategy will be the following: with TETRA MoU the spectrum lobbying is focused first to get additional bands (3+3 MHz for NB, 3+3 MHz for WB) in the 380…470 MHz area (Wählen, 2010). At the same time the application developers are encouraged to develop solutions which are optimized better concerning the utilization of the data link capacity. Compression technology solutions are used and developed to improve the performance of the data transmission. The lobbying for NB and WB frequencies will be followed by emphasizing the attention of the authorities on the missing BB frequencies, 2 x 10MHz in the area of <1 GHz. A part of the lobbying for the frequencies is also the building of trials to study and inform publicly the results of the tests.

6.2 Commercial Mobile Network Operators

Bet on Most probable scenario

The defined strategy for the *Most probable scenario* may – from the commercial operators' point of view – be quite attractive. It would create a lot of data communication for their networks, but not cause a need to upgrade the network to fulfil the high reliability and availability requirements. In any case if the commercial operators would see the mission critical communication business attractive they still have time to improve the reliability and the coverage of the network until the year 2015 - before the authorities start to roll-out their own BB networks.

Bet on Best scenario

The strategy for the *Best scenario* (best for PSS operators) is a threat to the commercial operators. The strategy is based on the assumption that PSS operators have in the 380…470 MHz band enough frequencies for the BB data service. In the rural areas there would be even extra capacity to sell to supply a fixed wireless service. The low frequency band (<470 MHz) would mean reasonable low network building costs, so in this scenario the possibilities of the commercial operators to sell mobile data services to the PSS agencies will stay minor. All in all, this scenario may lead to the competition conflict between the PSS and the commercial operators.

Hedge

The *Hedge* strategy has quite similar impacts to the commercial mobile operators than what the *Most probable* strategy has. It allows the commercial operators to start some new PSS service businesses and give some time for commercial operators to adjust their processes before the PSS operators make the decisions regarding their own BB network.

Preserve flexibility and Influence

The *Preserve flexibility* and the *Influence* are from commercial operators' point of view close to the *Hedge* strategy, except only pilots are made using the TEDS technology. This may give more room to promote the services that the commercial networks can offer.

6.3 PSS Mobile Technology Suppliers

Bet on Most probable scenario

The *Most probable scenario* strategy gives PSS mobile technology suppliers an immediate opportunity to start TEDS technology deliveries. Also the optimization of PSS applications to better utilize the available bandwidth is a new business possibility. The other parts of the strategy, i.e. the preparation of the LTE technology utilization, the utilization of multichannel routers and the utilization of commercial mobile operator networks are indications that the vendors of the commercial mobile networks will take an ever increasing part of the PSS communication business.

Bet on Best scenario

The strategy for the *Best scenario* (best for PSS operators) is challenging to the PSS vendors. If the PSS operators manage to obtain spectrum in the 400 MHz band for their BB data network, the WB network coverage may stay quite modest. This means that TEDS technology volumes will stay low and LTE technology takes the major role in future PSS network implementations. The analysis concludes that it is not to the benefit of the PSS mobile technology suppliers if the spectrum for PSS BB data is allocated in the 400 MHz band, i.e. the bet on *Best scenario* strategy is a threat to the PSS mobile technology suppliers.

Hedge

According to the *Hedge* strategy the TEDS networks for urban areas are rolled-out in 2013…2015. This gives the PSS mobile technology suppliers the possibility to establish the TEDS technology before any BB decisions have been made.

Preserve flexibility and Influence

Preserve flexibility and *Influence* are challenging strategies to the PSS mobile technology vendors, because only TEDS pilots are started and commercial mobile technology gets more time to overcome its limitations.

6.4 Commercial Mobile Technology Suppliers

Bet on Most probable scenario

The defined strategy for the *Most probable* scenario is seen attractive from the commercial operators' point of view. If so, it is attractive also from the vendor's point of view – the vendors who supply technology for commercial mobile networks. According to the strategy the operators prepare the roll-out of BB networks which are based on the commercial mobile technology, i.e. LTE.

Bet on Best scenario

The *Best scenario* strategy (best for PSS operators) is partly a threat to the commercial operators. But to the supplier of the BB technology which is intended to be utilized, it is not. The strategy would open the markets to the 400 MHz band LTE technology. The strategy is based on the assumption that PSS operators have enough frequencies in the 380…470 MHz band for BB data service. In the rural areas there would be even extra capacity to sell for fixed wireless service. The low frequency band (<470 MHz) would mean reasonable low network building costs, so in this scenario the PSS operator would not necessary need the data services from the commercial networks.

Hedge

The *Hedge* strategy has quite similar impacts on the commercial mobile technology suppliers than what the *Most probable* strategy has. It allows the commercial operators to start some new services businesses and some additional time for commercial operators to adjust their processes before the PSS operators make the decisions of their own BB network.

Preserve flexibility and Influence

The *Preserve flexibility* and *Influence* strategies are from a commercial mobile technology suppliers' point of view close to the *Hedge* strategy, except only pilots are made using the TEDS technology.

6.5 Application Suppliers

Bet on Most probable scenario

The defined strategy for the *Most probable scenario* is from the application suppliers' point of view acceptable. The main challenge will be that the applications have to work in all networks (TEDS, dedicated BB, commercial BB).

Bet on Best scenario

The *Best scenario* strategy is probably offering the application suppliers more business opportunities than any other strategy alternative. The data mobile communication is mainly based on the usage of the dedicated BB mobile network and offering a good platform to develop applications.

Hedge

The *Hedge* strategy has quite a similar impact on the application suppliers as the *Most probable scenario* strategy has.

Preserve flexibility and Influence

The *Preserve flexibility* and the *Influence* are from an application suppliers' point of view a challenging strategy, because only pilots are made using the TEDS technology and this will prevent the development and usage of new applications.

6.6 Combined Strategy – Conclusion

PSS network operator

The *Combined* strategy (Porter, 1985) from a PSS network operator's point of view, which is presented in Fig. 18, can be seen as a conclusion. The *Combined* strategy is formed by combining elements of the predefined five strategies. In this case the *Combined* strategy is mainly based on the *Most probable* and *Influence* strategies. The strategy forms a roadmap type of plan to achieve the optimum result.

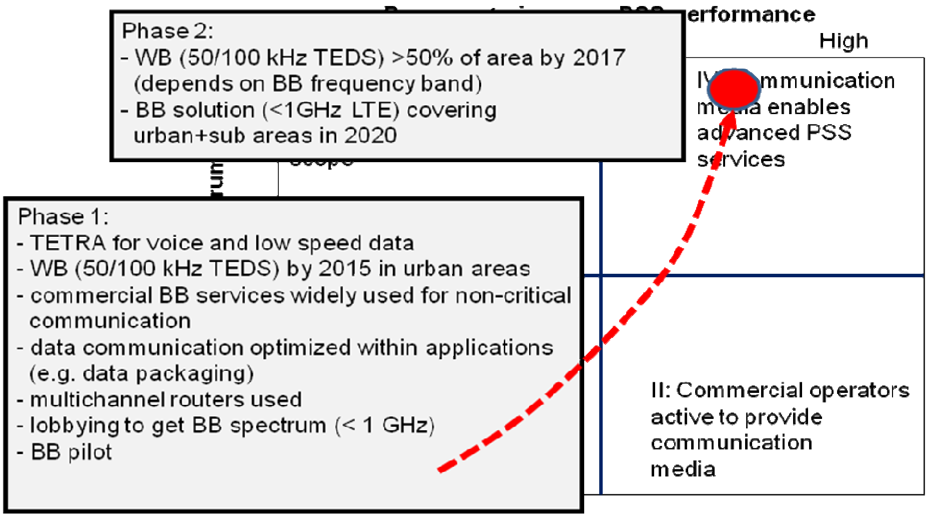

Fig. 18. Combined based mainly on the Most probable and Influence strategies

The present TETRA network infra is utilized as far as it is an economical solution for voice. The WB network will be built for the mission critical data based on TEDS with 50 kHz channels and will utilize the existing base station infra. Additionally the commercial cellular networks are utilized for non-critical data communication. The data transmission efficiency will be improved with the compression technology and optimizing data packing in applications. The lobbying is done to get a harmonized spectrum for WB and BB networks.

Later the WB network (100 kHz channels) will be completed based on the NB network base station infra and new allocated frequencies in the <470 MHz frequency band. The BB data network – using LTE technology - is built into urban and suburban areas; the frequency band is 10+10 MHz in the <1 GHz area. The density of the population guides the local technology choices and the coverage plans.

All in all the definition of the *Combined* strategy is done according to Porter (1985) by trying to be a first-mover (BB pilot), by keeping initial the competitive position (utilize the existing TETRA infra), to optimize the costs and resources (TEDS utilizes the existing infra), to keep the risks within an acceptable level (roadmap approach) and by understanding the threat of the alternatives (utilize commercial networks).

The Combined strategy and other stakeholders than the operator

The *Combined* strategy has quite similar impacts on stakeholders other than the operator (i.e. commercial mobile operators, PSS mobile technology suppliers, commercial mobile technology suppliers, application suppliers) as the *Most probable scenario* strategy has.

Chapter 7

Discussion

7.1 Methods

The purpose of the research was to study what the PSS mobile communication solution will be ten years from now. The chosen method is the scenario planning (Schoemaker, 2000), supported with the strategy review (Porter, 1985), which consolidates the scenario results. The interviews in the beginning of the research give essential input data for the study. The definition of strategies adds understanding of alternative cases and improves the credibility of the found scenarios. The results of the research show that the chosen method works reasonable well when searching an answer to the questions similar with this thesis (Heikkinen et. al., 2008a; Heikkinen, 2008b; Levä et. al., 2009).

7.2 Assumptions

The definition of the assumptions of the research problem (what will the PSS mobile communication solution be in ten years from now) is challenging - we should know what the real needs are, what service level we are targeting, what spectrum is available, what technology is available and how much we are ready to invest.

In this study the starting point of the research is that the existing emergency mobile networks are implemented using TETRA technology. The problem solutions are considered mainly from the network operator's point of view. If the view point would have been any other stakeholder than the operator, e.g. the PSS mobile system supplier or the end-user, the results were different. However, the operator – in this case equal with the society – is selected as a main stakeholder, because the operator makes the selection and investment decisions and in that way has a significant impact on the future alternatives.

7.3 Key Findings of Scenarios and of Strategies

The narrowband PSS mobile solution exists and will stay in the short and medium term; the recently built TETRA networks fulfil voice and slow data communication needs well. On the other hand, the specific voice functionality is quite complicated to implement with any future system – so the focus of the new PSS networks is on high speed mobile data networks (McEwen, 2009).

Certain key findings concerning the mobile data networks came out from the defined scenarios and from the defined strategies. In future, more heterogeneous solutions than those existing currently will be a new issue. The poor availability and security of commercial networks became clear during the study. The possible new spectrum, as well as budget financing have key roles in the evolution of PSS mobile data networks. The sequential timeline was partly surprising, but it solved the path dependence issue. Key findings are listed in the sections 7.3.1 – 7.3.6.

7.3.1 Needs of High Speed Data Communication

Some applications need higher data link capacity than currently available in TETRA networks (Table I). The wideband connection (50…200 kbit/s) is enough for most applications. Video, if widely used, will need the broadband mobile network for transmission. During the interviews the mobile command and control was seen as one of those new services which will be crucial in future and will be based on high speed mobile data communication (Hong Kong, 2010; Emergency Response, 2010; Police Technical, 2009).

When emergency network users utilize their private cellphones it creates expectations how the PSS mobile communication should work. The gap between the usability of TETRA and 3G services is remarkable and the difference will be huge when LTE networks are taken into use. This will cause pressure to increase bit rates in the PSS data communication network; otherwise there is a danger that the critical communication will be moved into the non-secured commercial networks.

7.3.2 Challenges in Utilization of Services of Commercial Mobile Networks

It is important to notice that the title “Utilization of Services of Commercial Mobile Networks” covers only the issue of whether the network is dedicated to the PSS agencies or if the services of the commercial network are used. It does not cover the question of what technology – PSS specific or a commercial one - fits best.

The commercial networks have many advantages: the networks exist, the coverage is excellent – even many networks cover the same areas, the indoor coverage is good, the data speeds offered by the network are very high, the terminal offering is good, the functionality of the terminals is excellent and the price level of the terminals is low.
However, the commercial mobile networks have some fundamental problems if the networks are used for PSS mobile communication.

One of the problems is that the networks become jammed in a disaster situation because a huge amount of subscribers try to reach their closest ones (Lavery& Horan, 2005; Swan&Taylor, 2003). One way to resolve the jamming problem has been to grant authorities the higher priority or even prohibit the calls made by ordinary people. If the commercial operator would be known of the priority adjustments during the emergency case, it may have problems to acquire commercial customers. Another drawback of the usage of priority is that it would lead to overloading of the emergency response centres simply because people would try to call to someone in any case. And if the mobile phone service is completely blocked from the public, then the public cannot give any warnings or alarms (NPIA, 2009).

Together with the jamming problem there is a continuous discussion of the underuse of the spectrum in the public safety and security networks – the full capacity is needed only when an incident happens. Because of this, there are proposals that commercial users would utilize the unused frequencies while the spectrum is not used by PSS agencies. The issue is that in the case of an emergency the traffic is increased dramatically by both user groups, by the commercial as well as public safety agencies. This seems to be forgotten in the discussion. The public-private partnership arrangement to share the spectrum and to build the PSS LTE mobile network has been a plan in the United States. If the business case can be implemented and the mechanisms are found to guarantee the needed capacity for the emergency agencies in the case of disasters, the model may be copied to Europe.

The LTE technology is capable of sharing the capacity of the same network elements between different operators – this might improve LTE's economics in PSS solutions. But if the used mobile trunk network is common with the commercial users, the overloading of the mobile trunk network is possible and especially if the normal Internet traffic is allowed to be routed through the same IP-trunks as the mobile network uses.

The other fundamental problems the commercial networks have are their capability to tolerate only short power supply breaks and to have long repair times. Both mean poor availability. The availability problem is too expensive to fix in wide cellular networks (NPIA, 2009).

When the commercial operator offers PSS mobile services which are based on the utilization of the commercial mobile network the business case is challenging. The tight security and availability requirements require additional investments yet the volume of the PSS subscribers is only a few percent of the total subscriber amount. Also the possible remedy fees may be difficult to define between the authorities and the network operator. The fine should be so high that it forces making the necessary investment – however, it should be acceptable from the business case point of view.

The security of the commercial networks is also an issue for the authorities. The ownership changes of the mobile network operator are an unknown security risk. A possible cyber attack is a risk, which is difficult to eliminate beforehand in commercial networks: these networks have enormous amounts of links to the surrounding environment.

All in all, the utilization of the commercial mobile networks have some benefits, but if the service is supplied for the PSS agencies, today there seems to be many fundamental problems in the availability of those networks.

7.3.3 Spectrum Availability

The additional spectrum (TETRA Association, 2010) and more investment money are both needed to get higher bit rates for PSS users in the emergency mobile networks. The lobbying has already started to get frequencies for the WB and BB data networks. The availability or non-availability of the additional spectrum for PSS mobile networks has a fundamental impact on the future alternatives of the new PSS mobile services and especially on the mobile high speed data services.

To keep the number of the base stations low and the additional investments within an acceptable level, it is crucial that the WB frequencies are in the area of 380…470MHz and the BB spectrum in the < 1GHz area. However, the emancipation of the frequencies will take years following the product development time (*Viestintävirasto*, 2009), the time needed for the purchasing decisions as well as the time for implementations. This will highlight the importance of the development of TEDS with the 50 kHz channel bandwidth and the need to improve the applications to minimize their data transmission volumes.

7.3.4 Development of Mobile Technologies for PSS Agencies

TETRA

Some of the newest nationwide TETRA networks will be completely rolled-out in the early 2010s. That means that those networks will be in operational use until the end of 2020s. On the other hand it can be seen that there is no other technology which includes the needed voice functionalities. The main issue in many cellular technologies to replace TETRA is the long latency time, but it seems to be solved in the LTE technology (NSN, 2010). It will be also important to notice, that when existing TETRA technology is replaced, a separate spectrum for that replacement is needed – in one form or other.

TEDS

In the best case TEDS can be rolled-out with marginal costs, i.e. only additional radio capacity is needed and the existing TETRA infrastructure can be used (Saijonmaa, 2009; Motorola, 2009a). In a few countries the needed free spectrum exists for a 50 kHz channel system (Suomen Erillisverkot, 2010), which makes quick implementation possible. The role of the TEDS technology will be a medium term mobile WB data solution in urban areas – until the BB solution exists – and a long term solution in rural areas. If the described roadmap is realized, then TEDS' volumes will stay low and also only the vehicle models of TEDS terminals will be available from the terminal suppliers.

Mobile WiMAX

Mobile WiMAX has no technology advantages compared, for instance, to the LTE technology (*Liikenne- ja viestintäministeriö,* 2009a). Because WiMAX has not reached any remarkable position in the markets, it will not benefit from the scale of economies in the way that LTE will.

Cognitive radio

The dynamic spectrum access and cognitive radio technologies are seen as a solution to allocate scarce frequencies for PSS mobile communication. The issue in the cognitive radio systems is that in cases of emergency all kinds of mobile communication will increase dramatically. It therefore appears that this technology would also need certain priority functionalities - with the problems they carry within (section 2.5).

LTE technology

The LTE technology will be used in the United States to build the BB mobile data network for emergency agencies. The spectrum band allocated for the service is in the

700 MHz area (Wyllie, 2010). The voice communication will be kept in the APCO P25 -technology networks – “It will be many years, if ever, before LMR (Land Mobile Radio) systems can be replaced entirely by broadband technologies” (McEwen, 2009). The benefit what the LTE alternative has is that the selected mobile data technology would be the same technology that will be widely used in commercial networks. That also means that the terminal offering is versatile and the price level stays low. The US solution as a role model may mean that the PSS BB mobile solutions will be copied to Europe. The LTE is also a potential candidate for the future PSS voice communication solution because with its short latency time it can fulfil the PSS voice communication call set-up time requirements.

7.3.5 Timing Considerations

Figure 19 represents the timing of the possible PSS mobile network alternatives.

The development of TETRA started in the early 1990s. The first roll-outs were done at the end of the 1990s and it still continues in many European countries - some of the biggest ongoing roll-outs are Germany’s and Norway’s networks. The lifetime of TETRA systems can be thought to last until the end of the 2020s - i.e. the TETRA networks will be up and running in many countries until the years 2025…2030. After that time all TETRA networks will have to be replaced either in the late 2020s or in the early 2030s.

One of the high speed data alternatives is the utilization of TEDS technology and the new PSS specific BB solution (Alt. 1 in Fig. 19); this will require additional spectrum. The additional spectrum for PSS mobile communication is possible to get in Europe sometimes between 2015 and 2020 (*Viestintävirasto*, 2009), meaning that at that time it will be possible to roll-out PSS specific BB mobile networks. The TEDS technology can be partly rolled-out earlier because some countries have extra spectrum capacity available in the frequencies allocated for TETRA.

The development of the 700 frequency band LTE technology for PSS purposes in the United States may have an impact on the future PSS BB technology selections in Europe - in the United States the frequencies in the 700 band have already been allocated for PSS usage.

If there are no direct frequency allocations, one alternative is the cognitive radio solutions (Alt. 2), which may be available in the 2020s.

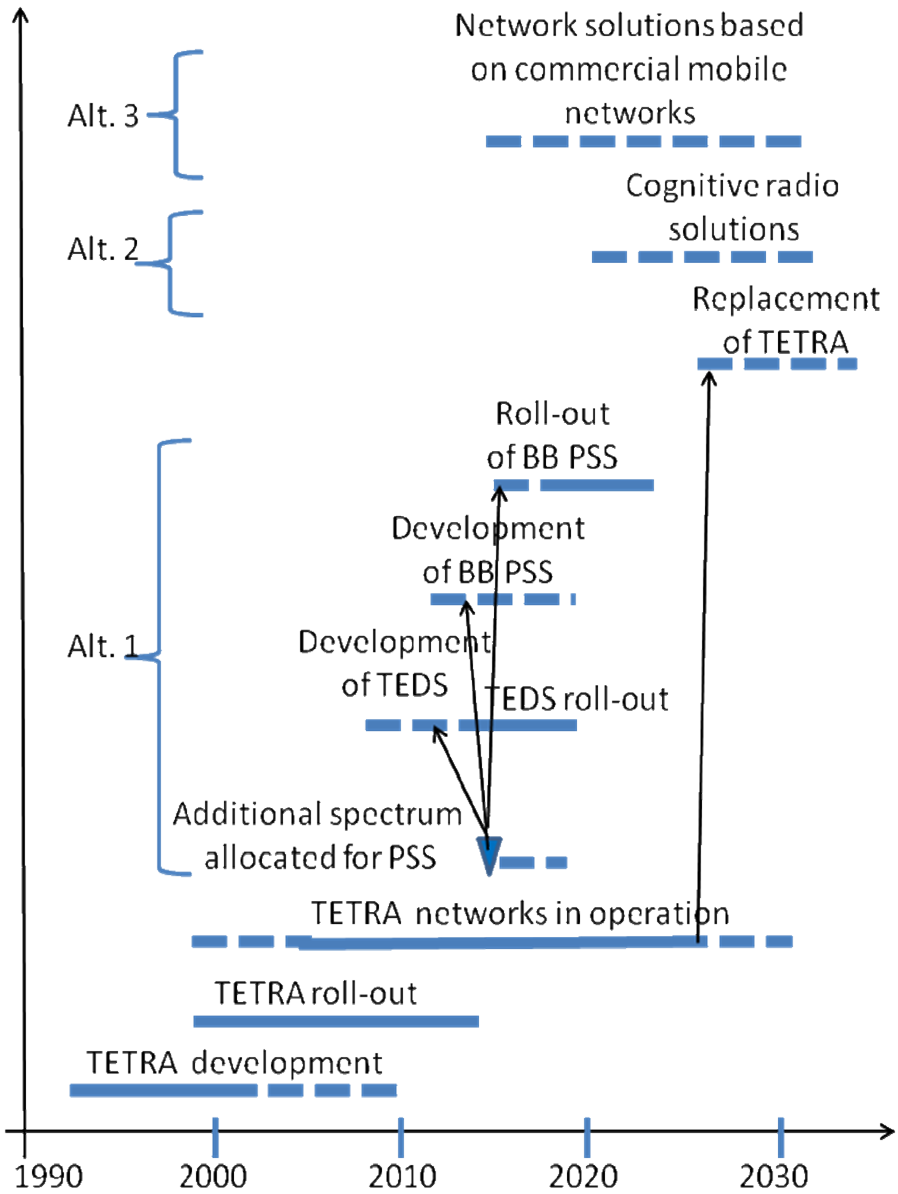

Fig. 19. Evolution timing consideration

The utilization of the commercial mobile networks (Alt. 3) as a media for PSS mobile communication is possible already today. However, in section 2.5 the possibilities of the usage of those networks as a mission critical communication media are seen as weak: because of the poor availability, only the non-critical communication is considered possible.

7.3.6 Network Architecture - Hybrid Solution

Based on this study, the PSS mobile communication networks may consist in future of a set of technologies (NB e.g. TETRA, WB e.g. TEDS, BB e.g. LTE, WLAN) - with appropriate coverage and capacity.

The wireless landscape will be more heterogeneous than earlier. This is also in line with Lehr et. al. (2009) who predict that future communication systems will be the combinations of many solutions.

The multi technology solution – a hybrid solution - would give an optimum price per value ratio (Fig. 1). The following conclusions are made from the network architecture's point of view:

- the NB mission critical networks, dedicated for voice group calls, have a role as a highly secured voice and low bit rate communication media – until they come to the end of their lifetime
- WB data network - implemented using the TEDS technology and based on the utilization of frequencies next to the TETRA spectrum band – is an economical solution (Saijonmaa, 2009; Motorola, 2009a) because the same base station sites can be utilized. It fulfils the tough availability requirements, it also fulfils data transmission needs in the medium term, and the development of the compression technology will improve its position.
- the commercial BB cellular network can be used and it is sensible to use for non-critical data transmission

- when the spectrum has been allocated for BB data network in <1GHz area, the mission critical BB data networks will be built based on commercial technologies (e.g. LTE)
- WLAN technology can be utilized locally for database download services and for building ad-hoc networks.

Chapter 8

Conclusions

8.1 Results

As stated in section 1.2, this thesis seeks an answer to the question: “What will the mobile network solution for PSS agencies be in ten years from now taking into account how the enhanced data communication needs can and will be fulfilled? At the same time, it needs bearing in mind that financial limitations, high security and availability requirements as well as the possible role of the commercial cellular networks all have to be considered in the final solution”.

The conclusions are presented in the following covering issues like: (1) high speed mobile data needs; (2) the need of the dedicated network; (3) the impacts of available spectrum and financing; (4) the network architecture and; (5) the conclusive roadmap.

Mobile command and control needs BB

The mobile command and control functionality, which is seen as a tool to improve the performance of the emergency agencies, needs a high speed data mobile communication network. And the video transmission service, whose actual function and mode in the task processes of the emergency agencies is still under the study, will be based on the BB data network.

Dedicated network is a must

The availability of the commercial networks is not on the level required for mission critical communication. The conclusion of the study is that although the commercial BB networks are feasible for non-critical communication, the emergency agencies need the dedicated network during their field operations for the voice and data communication.

Spectrum and financing have major impacts

The spectrum which is now allocated for voice and low speed data can only partially fulfil the WB mobile data communication needs and not at all BB mobile data requirements. The future WB and BB communications in PSS mobile networks need new spectrum allocation as has been proposed (2 x 3MHz for NB, 2 x 3MHz for WB and 2 x10MHz for BB). The spectrum allocation must be across the whole of Europe otherwise the equipment volumes will stay too low. The size of the allocated spectrum and its place in the frequency space (< 1GHz) has a major impact on the evolution of future PSS mobile networks. Without new frequencies, reliable secured BB mobile communication services for emergency agencies cannot be supplied.

The financing has as strong influence on the future of PSS mobile communication solutions than that which the spectrum allocation has. The technologies already exist, so when the frequencies are allocated the financing will set how wide the new networks are and what technologies are used.

PSS network will be heterogeneous

The future PSS mobile networks consist of several technologies (NB, WB, BB), all with appropriate coverage and capacity. All the implementation is based on the real needs in various geographical regions, meaning also that the network will be heterogeneous in the future. The utilization of the commercial networks for non-critical communication is possible and probable but the poor availability of the commercial networks will prevent the wider utilization of the public mobile communication services.

Conclusive roadmap

The NB/TETRA technology – on what many recently built PSS networks are based - will be used in Europe towards the end of the 2020s for voice and slow data communication. Latest then when the TETRA technology reaches its end of life cycle the voice functionality will be integrated into the BB solution.

WB/TEDS data network is an economical solution and can fulfil medium term data transmission needs in (sub)urban areas (50/100 kHz TEDS) in the 2012 to 2017 timeframe. When the dedicated BB networks are rolled-out between 2015 and 2020, TEDS can be used as an economical solution for rural areas – which, however, depends on the BB solution and its spectrum area. TEDS can be rolled out in the best case just by upgrading the existing TETRA system and utilizing the present TETRA infra.

The most probable BB solution for PSS mobile communication is the LTE technology (<1GHz LTE), which will be first taken into use in the United States. In Europe the spectrum for PSS BB is expected to be available in sometime between 2015 and 2018. The pressure to save investment costs may mean that LTE technology is used only in urban and suburban areas. LTE would be a good candidate also for the voice communication platform.

The defined scenario is a sequence of scenarios; technologies follow each others in a roadmap way. The sequence consists of the utilization of the existing extra TETRA spectrum for 50 kHz TEDS, following the better utilization of frequencies with enhanced data packaging. If new spectrum is allocated for WB, that makes possible the 100 kHz TEDS implementation. When the frequencies for the BB network (<1GHz) have been allocated between 2015 and 2018, the dedicated BB mobile data networks can be built. These can be based, for instance, on the LTE technology according to the US example.

8.2 Assessment of Results

The defined solution is determined by quite a few forces. The drivers who push the network to be more sophisticated are: (1) expectations, what the 3G/LTE technologies will cause to PSS mobile networks; (2) LTE technology rolled-out first in US as well as; (3) some new applications needing higher bit rate to function correctly, among other things the mobile command and control. The forces having a counter effect are: (4) lack of spectrum; (5) budget finance limitations; (6) the insufficient availability of the commercial mobile networks.

Because there are only 6 substantial forces, it makes the searching of the solution simpler. When analysing the possible outcomes of the listed forces, the defined scenarios and the developed strategies look as probable answers to the research question. The unexpected willingness of the governments to finance their own country-wide BB network for PSS usage would change the drawn schema – this might happen if new threats against the society would emerge. Another key force which could change the defined scenario completely is the unexpected result of the spectrum allocation.

8.3 Further Research

Study of the Return on Investment

The future PSS mobile networks consist of a set of technologies (NB, WB, BB) with appropriate technology, coverage and capacity. Further research should seek to find exact values for emergency services from society's point of view and how to make the appropriate risk assessment of the regions. Based on these values the emergency service level coverage and the network architecture can be defined so that they fulfil both minimum and optimum objectives. Having clarified this problem, society can then have the best return on its investment made to the PSS services.

Availability of the LTE network if the resources are shared

The LTE technology is capable to share the capacity of the network resources between more than one operator. A study of the behaviour of the network is needed where dynamics and availability of the system including the IP-trunk network are studied in the case where more than one operators - sharing the common resources – try heavily to overload the network.

Solutions to prevent disturbance, jamming and data corruption attacks

The existing PSS mobile networks have good encryption algorithms which prevent eavesdropping. However, the radio signal can be disturbed or someone may attempt to modify the content of the signal. The frequency hopping technology is one way to prevent such disturbances. It would be worthwhile researching especially how the low data rate communication solutions are capable of working in the high disturbance environment.

Reducing the amount of transported data

The study of the utilization of data compression and intelligent protocols is needed. The data transportation between the applications is not optimized, the part of data could often be downloaded beforehand or be coded more efficiently. Local databases could remove sometimes the needs to transport huge data blocks.

Appendix 1

List of Stakeholder Interviews

Title of the interviewee	Organization	Date of the interview
PSS mobile network operators		
Program Manager	A.S.T.R.I.D/Belgium	03.02.2010
Senior Coordinator	C2000/Netherland	03.02.2010
Standards, Quality control	A.S.T.R.I.D/Belgium	03.02.2010
CEO	RAKEL/Sweden	29.01.2010
CEO	Suomen Erillisverkot Oy	22.09.2009, 19.03.2010
CTO	Suomen Erillisverkot Oy	24.11.2009, 19.03.2010, 31.08. – 08.11.2010
Commercial mobile network operator		
Vice President	TeliaSonera	06.10.2009
Authorities		
Director of Rescue Services	MoI of Finland	09.09.2009, 18.03.2010
CTO	NPIA/UK	04.12.2009
CTO	Hong Kong Police	26.05.2008, 18.2.2010
User groups		
Inspector general	Police Technical Centre/ FIN	23.03.2009
Commissaris	Federal Police of Belgium	03.02.2010
Head of Hämeenlinna ERC	Hämeenlinna Emergency Response Centre	25.03.2010
System suppliers		
Senior Expert	EADS Secure Networks	06.11.2009
CTO office, Expert	EADS Secure Networks	06.11.2009
System Integrator		
Vice President	Pöyry Telecom	08.12.2009
Manager	Pöyry telecom	08.12.2009
Application suppliers		
Vice President	Logica	16.03.2010
Project manager	Logica	16.03.2010

Appendix 2

Interview Questions

The questions on this page are linked to Matti Peltola's Licentiate's Thesis named "Development of the radio communication for Emergency agencies". The study seeks to understand the most probable solutions in the time span 2020 +/- two years.

The questions:

1. Your existing radio network for emergency agencies
   - its status … and possible development plans
   - utilization of GSM/3G services

2. Please, list the forces, which are shaping the future of PMR networks
   1. What are the forces affecting the future?
   2. a) Which of these forces are greatest? – can you score them (1…5)
   2. b) Which of these forces are most uncertain? – can you score predictability (1…5)

3. Think again to question 2.
   Have you something to add to the list of forces, if you think through the areas:
   - political trends and uncertainties
   - economic trends and uncertainties
   - society(social) trends and uncertainties
   - technology trends and uncertainties
   - industry trends and uncertainties
   - end-user/functionality trends and uncertainties

4. List the top three external questions you would like to know

5. List and rank the 5 main functionalities which are used today in the network

6. List and rank 5 new (most important) functionalities which might taken in use in the next 5 years

7. What is your opinion of
   - usefulness of video service in field operations?
   - can field operation people have 2 terminals – instead of one
   - the role of commercial networks in your case
   - dynamic spectrum and cognitive radios ?

8. Could there be any Disruptive Solution replacing a part of the existing infra/services/devices which you could imagine to become true before the year 2020.

9. What are the 2 most important uncertainties?

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