InfoCom

Study of the mid- and longterm capacity requirements for wireless communication of German PPDR agencies

Final report

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1 Management Summary

Germany currently introduces for its PPDR agencies TETRA as digital professional radio system. This is designed for voice communication as well as the transmission of narrowband data. Beyond this numerous applications from the PPDR agencies cause additional communication requirements.

The study goal is to gather these additional communication requirements in order to derive from them a demand-driven frequency spectrum planning. Therefore the currently deployed TETRA technology as well as applications running on top of it, are outside the scope of this study. Based on the typical lead time for the frequency spectrum planning the gathering of the communication requirements is focused on the time period beyond 2015.

Performing the study first it has been important, that the demand gathering reflects a representative and therefore credible vision of the PPDR agencies. For this reason for the demand gathering 20 PPDR agencies from different sectors have been selected. The performance of the demand gathering has been done by “guided interviews”, as this method has several advantages, such as the possibility to explain the questions and therefore to ensure the “plausibility” of the given replies or to better analyse the gathered information based on the background knowledged collected during the interviews.

The information collected during the gathering of requirements have first been analysed statistically. This outlined several important results. The analysis clearly show, that a single communication technology cannot fulfil the whole range of user requirements, rather a combination of different communication technologies is required. These can be IEEE 802.11p, WLAN, technologies for a flexible ad hoc communication at the operation site in the 5 GHz band without dependency on infrastructures, technologies for the temporary inhouse radio coverage of buildings in the lower and middle MHz band, technologies from emerging cellular networks like LTE, satellite links and further specific technologies.

Furthermore it became clear, that nearly 75% of the communication scenarios are considered as “mission critical”, that is, their failure would immediately put life into danger. Also for nearly 90% of the communication scenarios a suitable communication network has to be highly available. This means that for these communication scenarios the usage of public networks, which are shared with commercial users, is not possible due to safety aspects. The operation of these public networks is not under control of PPDR agencies; therefore an overloading by commercial users, resulting in a possible unavailability for PPDR agencies and consequently a failure of the respective communication scenarios cannot be avoided.

Also strong requirements for broadband communication do exist. Nearly 65% of all communication scenarios have a bandwidth requirement of more than 1 Mbit/s, over 40% even a bandwidth requirement of more than 10 Mbit/s. 57% of the communication scenarios require a bandwidth of more than 1 Mbit/s over a range of more than 10 km. This underlines the requirement of long distance broadband communication, which could e.g. be fulfilled by emerging cellular technologies like LTE.

The subsequent analysis of the bandwidth and the frequency spectrum requirements derived thereof showed, that the realization of the theoretically maximal requirements is unrealistic. However, considering operational and strategical aspects of the user, as well as emerging technologies, a more realistic demand is obtained. This consists mainly of

- a frequency spectrum requirement of 60 MHz (20 MHz downlink, 40 MHz uplink) for a usage of LTE capacities exclusively by PPDR agencies,
- an additional frequency spectrum requirement of 60 MHz, preferable immediately above the frequency band from 5,15 GHz to 5,25 GHz, for the deployment of technologies for

the ad hoc communication at the operation site independent from any infrastructure networks, and

- a freqency spectrum requirement of about 14 MHz in a frequency band below 80 MHz for the temporary inhouse radio coverage of buildings.

For reasons of frequency economy, as well as for reasons of an efficient international collaboration these frequency spectrum requirements should be harmonized within Europe.

2 Study goal

Germany is currently in the process of introducing TETRA as digital trunked radio system for the PPDR agencies. This is designed for voice communication as well as the transmission of narrowband data.

Beyond this numerous applications from the PPDR agencies cause additional communication requirements. One example is the coverage of the operation site e.g. for the transmission of surveillance video information by mobile task forces or for the connection of command and control systems used by fire brigades or other rescue forces. Futhermore often the broadband connection of the operation site with central data bases is required in order to allow e.g. fire brigades the access to current data bases about hazardous material or data bases from car manufacturer containing guidelines about how to get access to the different car models with the jaws of life. Also advanced police vehicles request more and more an area-wide, permanent connection to the command centre in order to obtain information supporting the operation or to transmit realtime video information from the operation site to the command centre. The coverage of the operation site includes often also the ad-hoc inhouse coverage of buildings, to allow the transmission of telemetry data from the respiratory protection devices or of thermal image camera data from inside of buildings to the respective mobile command vehicles.

The study goal is to gather these additional communication requirements in order to derive from them a demand-driven frequency spectrum planning. Therefore the currently deployed TETRA technology as well as applications running on top of it, are outside the scope of this study. Based on the typical lead time for the frequency spectrum planning the gathering of the communication requirements is focused on the time period beyond 2015.

An important aspect of this study is to perform the succeeding realization of the determined frequency spectrum requirements in a harmonized way within Europe. This harmonization has many advantages. On the one hand side the scarce and valuable resource of the frequency spectrum will be used efficiently by the PPDR agencies in Europe. Furthermore it is necessary to use internationally the same frequencies in order to allow an efficient cross-border collaboration of PPDR agencies. Finally the usage of harmonized frequencies results in a bigger market for the respective products, which typically has a positive impact on their costs.

3 Procedure for the demand gathering

First it is important, that the demand gathering reflects a representative and therefore credible vision of the PPDR agencies. For this reason for the demand gathering 20 PPDR agencies from different sectors have been selected. During this attention has been paid to the fact, that the selected PPDR agencies cover sufficiently their sector, and are therefore representative enough. Among others it has been important, that the PPDR agencies are working innovatively, and are therefore able to give a good estimation about the future communication requirements beyond 2015. The 20 PPDR agencies are composed of the federal police and some state polices, special task forces, company, professional and voluntary fire brigades, rescue services, civil protection and disaster prevention and the Federal Agency of Technical Relief, customs and the Federal Offices for Goods Transport, as well as some other special forces.

The performance of the demand gathering has been done by “guided interviews”, as this method has several advantages. For example it minimizes the probability to obtain “wish lists” as it is often the case for many questionnaire methods. Performing a guided interview offers the possibility to scrutinize the plausibility of the given replies. Furthermore within guided interviews the questions can be explained properly, avoiding thereby very optimistic or very pessimistic interpretations, and achieve this way comparable and representative user replies. Finally guided interviews provide also exhaustive additional background information concerning the given replies, which are specifically for the later analysis extremely valuable. Attention has been paid in each interview to have from each PPDR partner persons participating, which have expertise concerning operational and strategical aspects as well as concerning communication technologies. For this reason typically several persons attended the interviews.

For gathering the communication requirements within the interviews it has been distinguished between 3 different operational categories, as those differ significantly concerning their communication requirements:

- **Normal operation:** This reflects the daily operation of the respective PPDR agency, which takes place with normal personnel resources separately from other PPDR agencies, and therefore results in a lower density of the operation forces.
- **Demonstrations and mass events:** Within scenarios of this operational category several PPDR agencies collaborate together at the operation site, each of them with high personnel placement, resulting in a high density of operation forces. Additionally in this kind of scenarios the overloading of public communication networks like cellular systems by commercial users has to be expected, leading to their unavailability for PPDR agencies. Characteristic to this kind of scenarios is that the operation can be planned time-wise in advance, allowing some precausions to be done.
- **Natural and major disasters:** Also within this operational category several PPDR agencies collaborate together at the operation site, each of them with high personnel placement, resulting in a high density of operation forces. Additionally in this kind of scenarios beside the overloading of public communication networks by commercial users it also has to be expected, that several communication networks relying on any infrastructure can fail, as their respective infrastructure has been damaged or destroyed. For example after a flooding the power supply may fail, affecting also base station of cellular networks. Finally operations within this operation category can no longer be planned time-wise in advance, preventing to do any specific precausions.

For all these 3 operation categories for each PPDR agency the communication requirements have been gathered separately. This doesn’t mean that each PPDR agency is represented in all 3 operation categories, for example, the Federal Offices for Goods Transport typically has

scenarios as normal operation, but no specific scenarios during demonstrations and mass events or during natural or major disasters. For the determination of the communication requirements first the respective user applications within the 3 operation categories have been identified. Each of these user applications has been assessed together with the interview partners concerning different aspects, such as

- the communication relations between the users, that is, who communicates with whom, resulting in an assignment of the application to a certain communication scenario,
- the area to be covered for communication, respectively in the case of directional radio links, the distance to be bridged,
- the required bandwidth,
- the acceptable connection establishment time and the delay of the communication connection, or
- the required availability of the communication connection respectively a possible requirement concerning the exclusive usage by PPDR agencies.

Where appropriate, for the determination of communication requirements single user applications have been already aggregated. For example PPDR agencies required the connection of police cars to the command centre in order to run different applications over this connection, such as the performance of data capturing tasks, data base requests, video transmission from the integrated cameras to the command centre or the transmission of status information of the police car. For these different unser applications the respective communication requirements have been aggregated, as finally the connection of police cars to the command centre for all applications should be done using the same communication technology. In order to handle this efficiently, generic communication scenarios have been specified in advance. Together with the interview partners the assignment of their user applications to one or more of the specified communication scenarios has been done. In case such an assignment hasn't been possible, existing communication scenarios have been extended or new communication scenarios have been added. Chapter 4 contains a detailed description of these communication scenarios.

The communication requirements gathered this way together with the users have been used as basis for the subsequent statistical analysis of these requirements, the determination of the bandwidth requirements within the 3 operation categories, and finally the derivation of the frequency spectrum requirements for the realization of the bandwidth requirements based on existing or emerging communication technologies.

4 Description of the communication scenarios

Basis for the interviews were pre-defined communication scenarios. Each scenario describes which partners communicate together, where these communication partners are located, and which communication and information paths are resulting.

The defined communication scenarios were grouped in 3 different categories:

- **Category A: Normal operation of the public protection and disaster relief (PPDR) agencies**
- **Category B: Mass cultural or sports events and demonstrations**
- **Category C: Natural and other major disasters**

It has to be considered that in the aspect of communication paths there are hardly differences between the communication scenarios of these categories. But changed additional conditions result in significant differences regarding the number of the communication partners, the usability of civilian network infrastructures, the inter-communication between several PPDR agencies, and the used application and services.

4.1 Category A: Normal Operation of the PPDR Agencies

Additional condition for this category:

Concerning the communication scenarios in this category the following additional conditions are valid:

- The concentration of the operational forces is lower than at mass events, demonstrations, natural or major disasters.
- Generally, in these communication scenarios a PPDR agency does not communicate with other PPDR agencies.

4.1.1 Scenario A1: Data communication from the control center or headquarters to the on-site operational forces

In this scenario the main issue is the data communication from a control center or headquarters to the operational forces at the operation scene which can consist of one or more team members of a PPDR agency. The team members use end devices that are connected to the control centre or headquarters via wireless technology (see **Fehler! Verweisquelle konnte nicht gefunden werden.**).

The control center can be located nearby or many kilometers away. The main data is transmitted via the downlink.

The team members can operate either in urban or rural environment. In some cases, the operation can even take place in mountain regions, e.g. for operations of the rescue service or even the mountain rescue service.

Figure 4-1: Scenario A1: Data communication from the control center or headquarters to the on-site operational forces

In such an operation the possible services and applications differ between the PPDR agencies. In the following some examples are listed:

- To operate efficiently the fire brigade needs the latest information concerning the operation scene, e.g. evacuation routes, building plans, plans of fire hydrants, hazardous materials instructions, or information about the optimal procedure to free trapped passengers after a car accident. Thus, a possible application is the access to central data bases.
- The police often needs to control suspects during their operations. For this purpose a central data service (e.g. the POLAS database in Germany) provides access for the on-site operational forces and can be used for a mobile check of finger prints, license plates, “wanted” pictures, etc.
- Health care of injured people is the highest priority for the rescue service. The online access to databases containing information about medicines or patients can support a more efficient and thus quicker treatment. In this context of course special attention has to be paid to the data protection of confidential personal data.

4.1.2 Scenario A2: Data communication from the on-site operational forces to the control center / headquarters

In this scenario the main issue is the data communication from the operation scene to the control center / headquarters. Thus, the main data is transmitted via the uplink. This fact is important because many communication systems provide a high data rate for the downlink but only a small data rate for the uplink.

Also in this scenario the control center can be located nearby or many kilometers away. The forces can operate in urban or rural environment. In some cases, the operation can even take place in mountain regions, e.g. for operations of the rescue service or even the mountain rescue service.

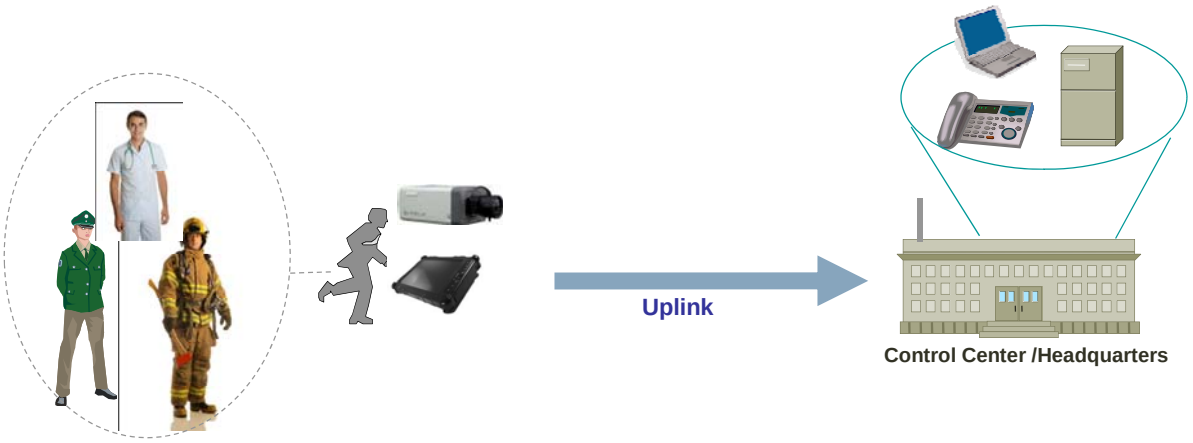

Figure 4-2: Scenario A2: Data communication from the on-site operational forces to the control center / headquarters

In this scenario a typical application is the transmission of video or picture data from the operation scene into the headquarters (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). For this purpose, a variety of different cameras types are available. Besides the video transmission also sensor data are important. In the following, examples of possible services and applications are listed:

- In order to prepare rescue actions or a surgery it is advantageous to transmit information concerning the condition of the patient as well as the done treatment already during the transport into the hospital by ambulance. This information can be transmitted as image data or data provided by measurement devices. Additionally, the transmission of these data is important when consulting an external specialist, e.g. to support the treatment in the ambulance.
- For the purpose of archiving or for a quick and time-sensitive analysis the police transmit data collected by the crime scene unit (e.g. finger prints, pictures of tire profiles, and so on) into the headquarters.

4.1.3 Scenario A3: Communication between vehicles and operational spots at the operation scene

In this scenario the main issue is the communication at the operation scene for a direct data exchange between several vehicles or operational spots. The vehicles can either be mobile or stationary. Operational spots can be temporarily established command centers but also stationary installed cameras or sensors.

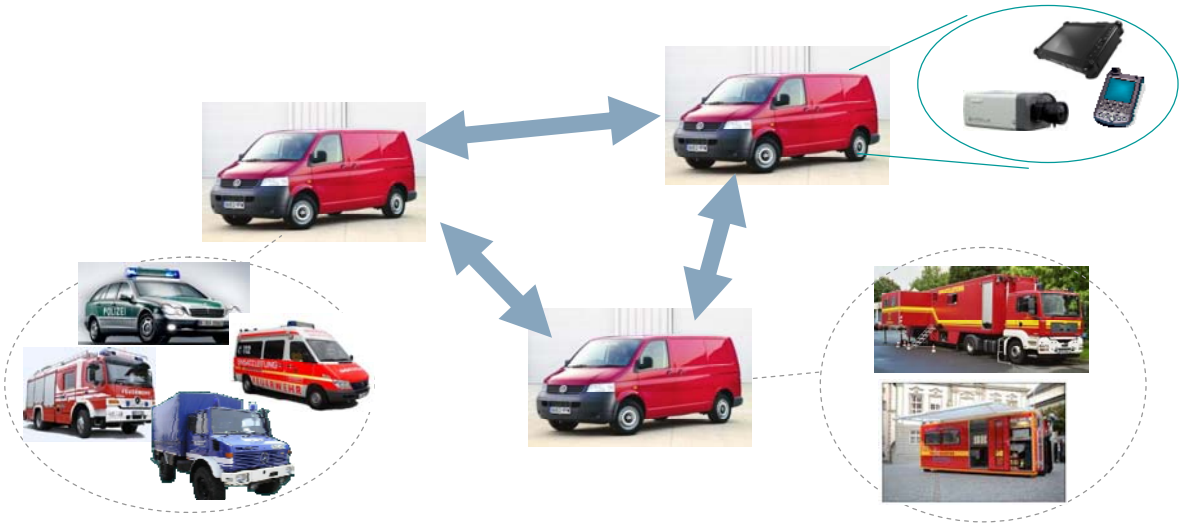

Figure 4-3: Scenario A3: Communication between vehicles and operational spots at the operation scene

In the following, some examples for possible services and applications are described:

- The on-site operational spots communicate with each other by voice. This application is relevant for e.g. fire brigades if there are several mobile command centers equipped in vehicles participating the operation. But voice communication between different operation vehicles is also necessary for other PPDR agencies, e.g. the police.
- For NBC reconnaissance forces (of the Federal Office of Civil Protection and Disaster Assistance in Germany (BBK) or the fire brigades) a quick analysis of the NBC measurement results is essential to alert or to give the all-clear. For this purpose, a real-time transmission of measurement results from the NBC measurement / reconnaissance vehicles to a vehicle that is responsible for the collection and analysis of the data or to an on-site operation vehicle can be realized.
- Mobile surveillance of objects and persons is necessary for the police special response unites. Therefore, video or picture data (e.g. from thermal imaging cameras, night vision cameras, or PTZ-cameras) can be transmitted between the operational spots. In the case of a covered surveillance operation a mobile special response unit benefits from the video transmission from cameras that are installed in unmanned vehicles near the object to a manned vehicle that is positioned outside the visual range.
- Dependent on the dimension of the operation, a video transmission from one or more cameras located directly at the trouble spot to a mobile on-site coordination center can support the fire brigade to get an overview about the current situation. Besides normal cameras here also thermal imaging cameras are important.

4.1.4 Scenario A4: Communication between individuals at the operation scene

In this scenario the main issue is the communication between individual persons, e.g. individual policemen, fire fighters, or medics that are not assigned to special operating resources (vehicles). Thus, each person has to carry an own communication device. The number and concentration of the communication partners can be significantly higher than in scenario A3. The direct communication between members of different PPDR agencies is not considered in this scenario but in the categories B and C. The very time-critical data transmission, e.g. of voice communication or data generated by the monitoring of respiratory protection devices, poses often a further challenge to this scenario.

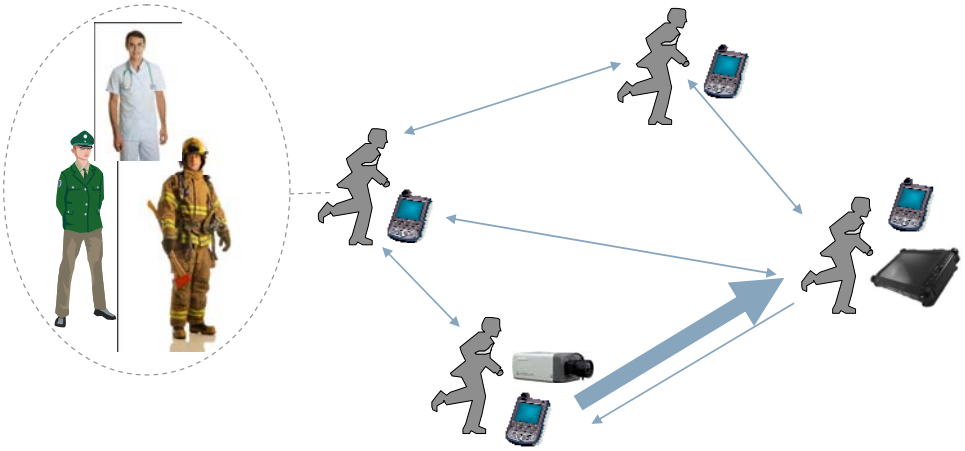

Figure 4-4: Scenario A4: Communication between individual persons at the operation scene

In the following, examples of possible services and applications are described:

- In many police operations video information is used for a better illustration of the on-site situation. Based on this information e.g. a police action or intervention can be initiated or commands to snipers can be given.
- There are many applications commonly used by the PPDR agencies. E.g. a fire fighter, a medic, but also a policeman communicates with his colleagues via voice, sends text messages, or exchanges documents (e.g. commands or status reports). Small hand-held devices like mobile phones or PDA´s are used for the communication.

4.1.5 Scenario A5: Operation in tunnels / buildings / cellars

This communication scenario considers the data transmission between communication partners that can be inside tunnels, buildings, or cellars. In such an environment the wireless communication is affected e.g. by the construction of the building (walls, ceilings) that results in an attenuation of the wireless signal. Already today this effect is a well-known topic because the analogues radio as well as the digital radio, that is currently established, does not provide a complete in-house coverage.

Inside the buildings mainly individual persons act as communication partners. Whereas, in the outside persons, vehicles, temporary on-site command centers or remote control centers participate the communication (see **Fehler! Verweisquelle konnte nicht gefunden werden.**).

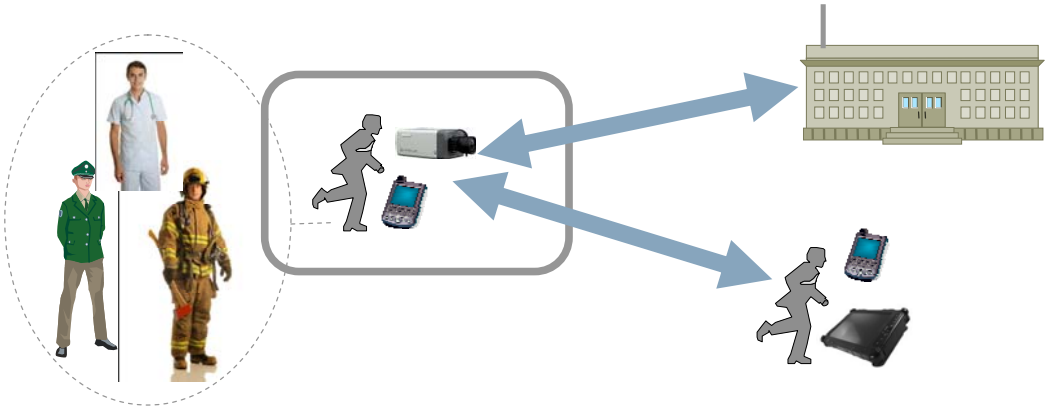

Figure 4-5: Scenario A5: Operation in tunnels / buildings / cellars

In the following, some examples for possible services and applications are described:

- Rescue operations of the fire brigade or the Federal Agency for Technical Relief (THW) often take place in burning or collapsed buildings or tunnels. The following applications are possible for the coordination and for the support of the operational forces:
  - Voice communication and accordingly the exchange of news or other messages.
  - Transmission of pictures from inside to the outside, e.g. pictures captured by a night vision or thermal imaging camera.
  - Transmission of sensor data of a monitoring system for respiratory protection devices from inside to the outside.
- Police special response units have often the requirement to keep persons or a crime scene (e.g. at a hostage-taking) under surveillance by using video or other sensor data (e.g. acoustics). These transmitted data support to assess the on-site situation. The persons or such a crime scene to be observed can be located inside buildings, cellars, or tunnels.

4.1.6 Scenario A6: Access to information from the internet and accordingly communication with external partners

In this scenario the main issue is the access to networks that are not owned or operated by the PPDR agencies (e.g. the internet) or the communication with external consultants or institutes directly with the on-site operating forces.

This scenario does not consider the case that the communication is established first to the control center and in a second step from there to the external networks or persons. Because in this case the wireless communication is mainly limited from the operation scene to the control center / headquarters (cp. scenario A1 and A2). Generally, the data will then be forwarded from there into the internet by wire.

The security aspect is one of the challenging aspects of this scenario because in this constellation it is not possible to use security mechanisms or keys that are specific for the PPDR agency when accessing external networks. Generally, civilian communication networks are not operated by the PPDR agency and often offer only insufficient security mechanisms. Furthermore, it is often difficult to estimate how reliable data bases are that are open for public access.

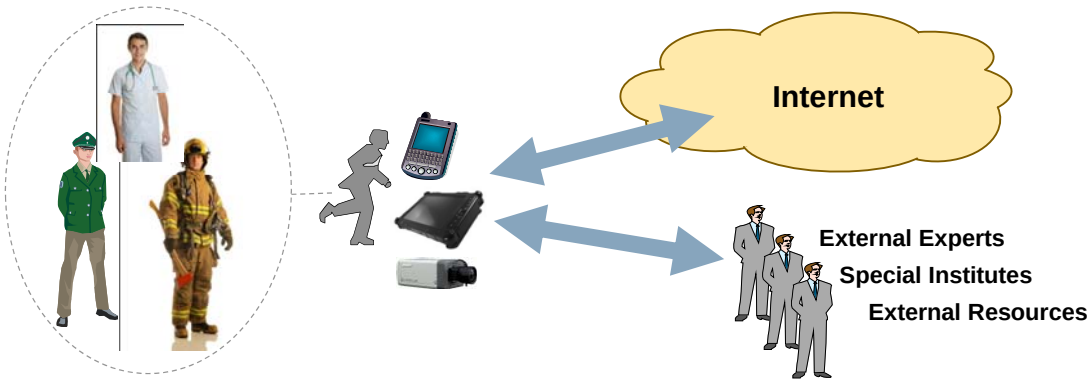

Figure 4-6: Scenario A6: Access to information from the internet and accordingly communication with external partners

In the following, examples for possible services and applications are described:

- In many rescue missions, e.g. in business or industrial areas, detailed information about the on-site conditions like layout of roads, access and exit routes, or positioning of the buildings is not up to date on regular maps. The internet websites of the respective business or industrial areas often provide significantly more detailed information.
- Information generated during the operation (pictures, reports, video, etc.) can be forwarded to external, consultant experts who are not directly connected to the network infrastructures of the PPDR agencies.
- According to the operation further information like congestion alerts, weather reports, telephone directories, opening hours, or local service providers (special cranes, bulldozers, etc.) can support an efficient operation handling.

4.2 Category B: Cultural or Sports Mass Events and Demonstrations

Additional condition for this category:

Concerning the communications scenarios in this category the following additional conditions are valid:

- The event is known in advance. If required, this circumstance enables to establish communication systems and communication links already in the run-up to the event.
- Civilian visitors of the event or demonstration will frequently use the civilian communication systems, e.g. the public land mobile network (PLMN). In consequence, an overload of the civilian communication system is possible. In this case, the system is also not available to the operational forces of the PPDR agencies if needed.
- If required, the number of team members and the concentration of the operational forces can be very high. In consequence, many communication links have to be possible in parallel.
- Different PPDR agencies attend the operation that results in the need of a common coordination and communication possibility.

4.2.1 Scenario B1: Data transmission from the control center / headquarters to the on-site operational forces

In this scenario the main issue is the data transmission from a control center or headquarters to the on-site operational forces. For this purpose, the team members use end devices that are connected wireless to the control center or headquarters. The main data direction is the downlink from the control center / headquarters to the operation scene (cp. chapter 4.1.1).

In contrast to scenario A1 during a mass event or a demonstration the general and additional conditions differ (see above), e.g. generally the number and concentration of the operational forces is significantly higher, different PPDR agencies operate together, and civilian communication networks are often not available due to overload. But the event is known in advance and thus predictable.

For instance, the alerting by pager of team members by the control center / headquarters is a possible application. Besides the alerting, also operation-specific information can be distributed (e.g. information about the location and also operation plans). Also alerting systems that support acknowledgement functionality are used. In this application example the needed data rate per alerted person is very limited, but it has to be ensured that many persons can receive these data simultaneously.

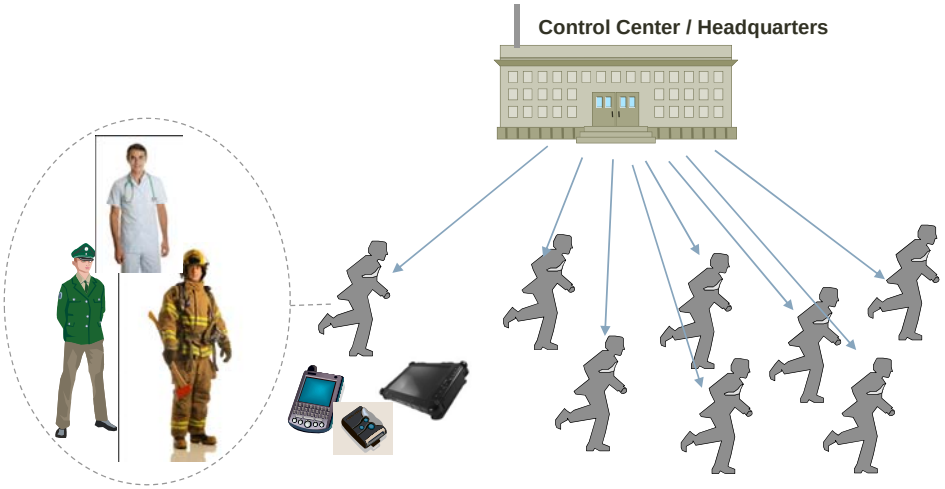

Figure 4-7: Scenario B1: Example „Alerting“

4.2.2 Scenario B2: Data transmission from the on-site operational forces to the control center / headquarters

In this scenario the main issue is the data transmission from the operation scene into the control center or headquarters. Thus, the main communication need is via the uplink (cp. chapter 4.1.2). In contrast to scenario A2 the general and additional conditions related to a demonstration or mass event are given (see above). Thus, further applications and services in addition to the mentioned ones in chapter 4.1.2 result from these conditions.

An example is the data transmission of numerous (sometimes high-definition) video streams of cameras that are pre-installed at the venue into the control center for the purpose of surveillance or assessment of the current situation. The video data enables the operational forces of the rescue service or the police to a rapid and efficient intervention. In addition, there is the possibility to store the video data for a later analysis. Besides the direct video transmission from the cameras into the control center or the headquarters the data also can be collected at a mobile or temporarily established command center and transmitted from there to the control center (see **Fehler! Verweisquelle konnte nicht gefunden werden.**).

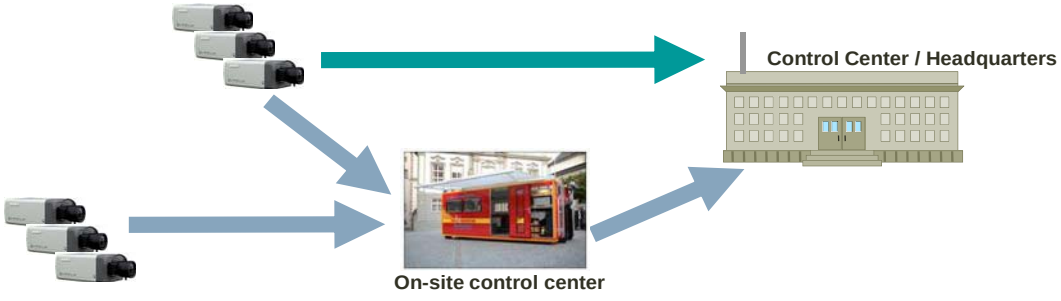

Figure 4-8: Scenario B2: Example „Pre-installed cameras“

One further example is the video transmission from a helicopter or an unmanned aerial vehicle (UAV) into the control center or headquarters. Due to the aerial view the situation of the event or demonstration can be monitored and assessed in the control center. Furthermore the video data can be stored there for the purpose of a later analysis.

During such operations helicopters and accordingly UAVs often fly in high altitude and possibly with high speed.

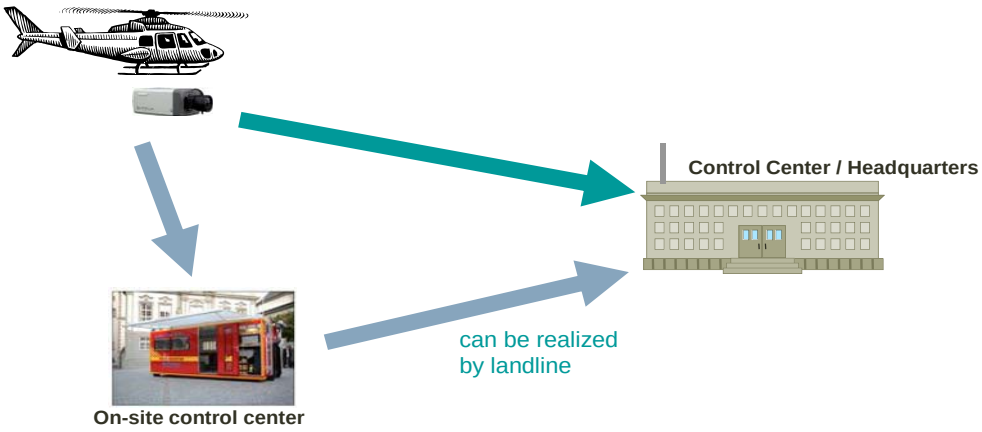

Figure 4-9: Scenario B2: Example „Video transmission from a helicopter / UAV into the control center"

4.2.3 Scenario B3: Communication between vehicles and operational spots at the operation scene

In this scenario the main issue is the communication between multiple vehicles or operational spots at the operation scene (cp. **Fehler! Verweisquelle konnte nicht gefunden werden.**). In contrast to scenario A3 the general and additional conditions related to a demonstration or mass event are given (see above). Thus, further applications and services in addition to the mentioned ones in chapter **Fehler! Verweisquelle konnte nicht gefunden werden.** result from these conditions.

One of these applications is the data connection between mobile control centers and accordingly rescue centers at the venue. In case of an emergency the operational forces can be alerted targeted and efficiently and also coordinated e.g. by voice communication or special command and control software systems like Ruatti 4C. In this scenario it is also possible to coordinate the different PPDR agencies participating the operation by a common command center.

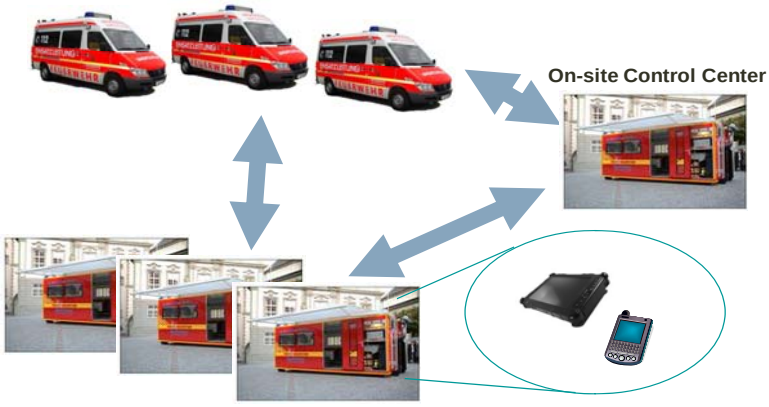

Figure 4-10: Scenario B3: Example „Connectivity between vehicles and on-site mobile control centers or rescue centers“

One further example is the data connection within a mobile convoy to provide escort to very important persons (VIPs) who intend to visit the event. Due to the video transmission from the leading vehicles to the other vehicles the following forces are able to assess the situation in a better way. In addition, also coordination or alerting by voice communication could be a reasonable application.

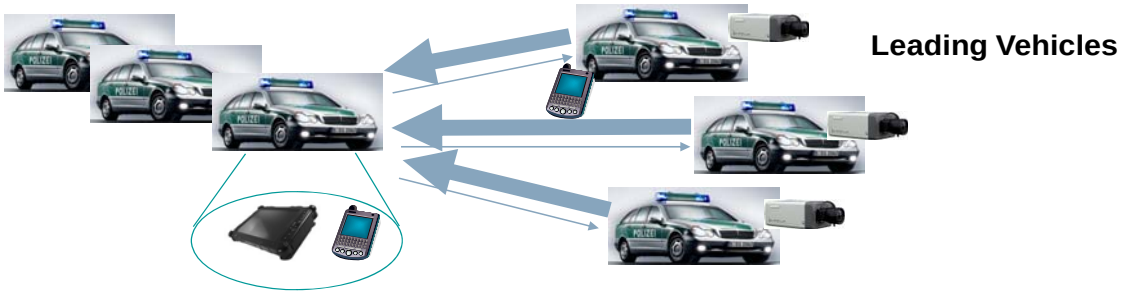

Figure 4-11: Scenario B3: Example „Data communication within a convoy“

4.2.4 Scenario B4: Communication between individuals at the operation scene

In this scenario the main issue is the communication between individuals, e.g. individual policemen, fire fighters, or medics that are not assigned to special operating resources (vehicles). Thus, each person has to carry an own communication device (cp. chapter 4.1.4).

In contrast to scenario A4 the general and additional conditions related to a demonstration or mass event are given (see above). E.g. the number and concentration of the communication partners can be significantly higher than during normal operations. Also the direct communication between persons of different PPDR agencies is in this scenario possible (e.g. for coordination purpose). As mentioned above during a mass event or demonstration the civilian communication networks are often overloaded and thus not available for the PPDR agencies if needed. This circumstance has to be considered when evaluating if a current existing network fulfils the requirements during operation. However, the event is predictable and thus the communication systems to be used can be selected and prepared.

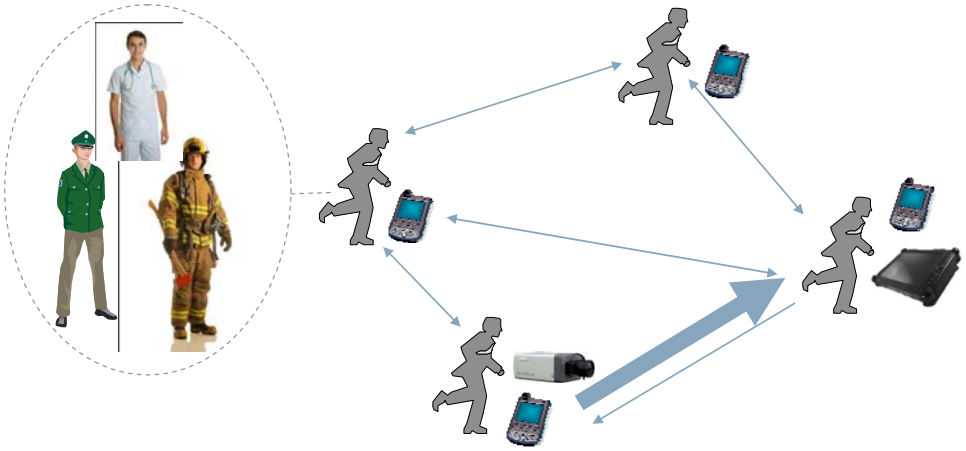

Figure 4-12: Scenario B4: Communication between individuals at the operation scene

4.2.5 Scenario B5: Operation in tunnels / buildings / cellars

This communication scenario considers the data transmission between communication partners that can be inside tunnels, buildings, or cellars. In such an environment the wireless communication is affected e.g. by the construction of the building (walls, ceilings) that results in an attenuation of the wireless signal.

Inside the buildings mainly individual persons act as communication partners. Whereas, in the outside persons, vehicles, temporary on-site control centers or remote control centers participate the communication.

In contrast to scenario A5 the general and additional conditions related to a demonstration or major event are given (see above). For instance, the event takes place inside a building but the operational forces have to be coordinated from outside.

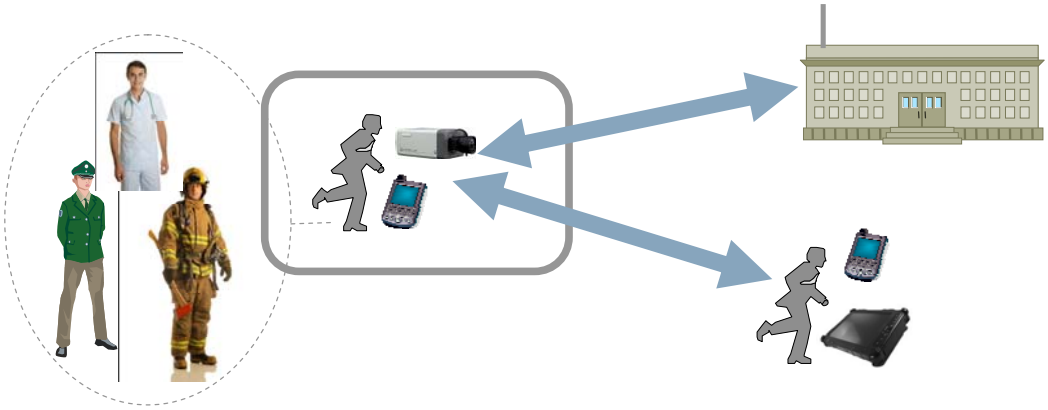

Figure 4-13: Scenario B5: Operation in tunnels / buildings / cellars

4.2.6 Scenario B6: Access to information from the internet and accordingly communication with external partners

In this scenario the main issue is the access to networks that are not owned or operated by the PPDR agencies (e.g. the internet) or the communication with external consultants or institutes

directly with the on-site operational forces. This scenario does not consider the case that the communication is established first to the control center or headquarters and then from there to the external networks or persons. Because in this case the wireless communication is mainly from the operation scene to the control center / headquarters (cp. scenario B2 and B3). Generally, the data will then be forwarded from there into the internet by wire.

As described in scenario A6 the main challenge here is the data security because generally civilian communication networks are not operated by the PPDR agencies.

In contrast to scenario A6 the general and additional conditions related to a demonstration or mass event are given (see above).

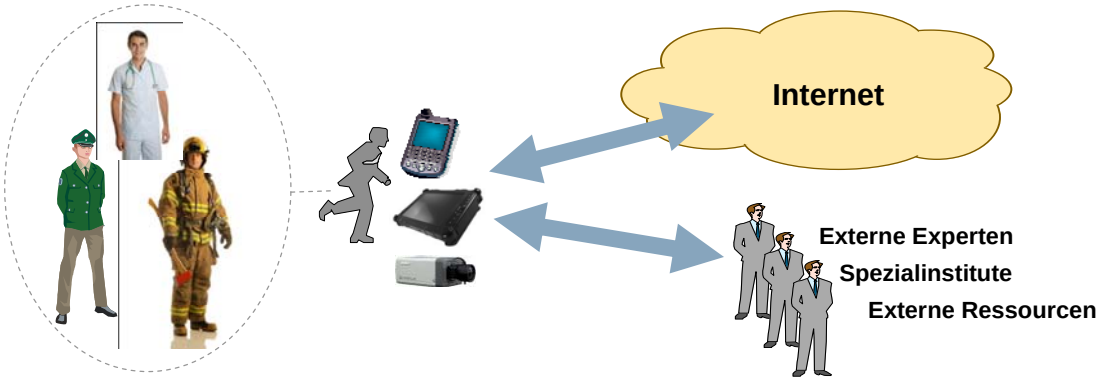

Figure 4-14: Scenario B6: Access to information from the internet and communication with external partners

4.3 Category C: Natural and Major Disasters

Additional condition for this category:

Concerning the communications scenarios in this category the following additional conditions are valid:

- A natural or major disaster cannot be planned.
- Normally, many civilians use the civilian communication systems (e.g. the public land mobile network) to speak with their relatives or friends. Thus, an overload of the network is probable. In this case, the result would be that the civilian networks are not available for the PPDR forces during their operation.
- A pre-installed communication infrastructure can be destroyed and thus would be not available for the PPDR forces.
- The number of team members and the concentration of the operational forces are possibly very high whereby many communication links in parallel are required.
- Different PPDR agencies operate together. This requires that they have to be coordinated accordingly and communicate together.

4.3.1 Scenario C1: Data transmission from the control center / headquarters to the on-site operational forces

In this scenario the main issue is the data transmission from a control center or headquarters to the on-site operational forces. For this purpose, the team members use end devices that are connected wireless to the control center or headquarters. The main data direction is via the downlink from the control center / headquarters to the operation scene (cp. chapter 4.1.1).

In contrast to scenario A1 here the general and additional conditions related to a natural and major disaster are given (see above), so e.g. normally the number and concentration of the operational forces is significantly higher, it is a common operation of different PPDR agencies, and pre-installed communication infrastructures are often affected or destroyed. In contrast to an event or demonstration in this case the date of the operation is not predictable and thus the operation cannot really be prepared.

In addition to the services and applications mentioned in chapter 4.1.1 there are several more possible. One example is the operation of a common control center or headquarters used by several PPDR agencies to assess the common situation (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). Afterwards, the information of the current situation can be forwarded to the different PPDR agencies. This information can consist of e.g. area maps, pictures, location data, reports, news, etc. Furthermore, a common command and control system can be used for the purpose of planning, coordination and leading of the different PPDR agencies.

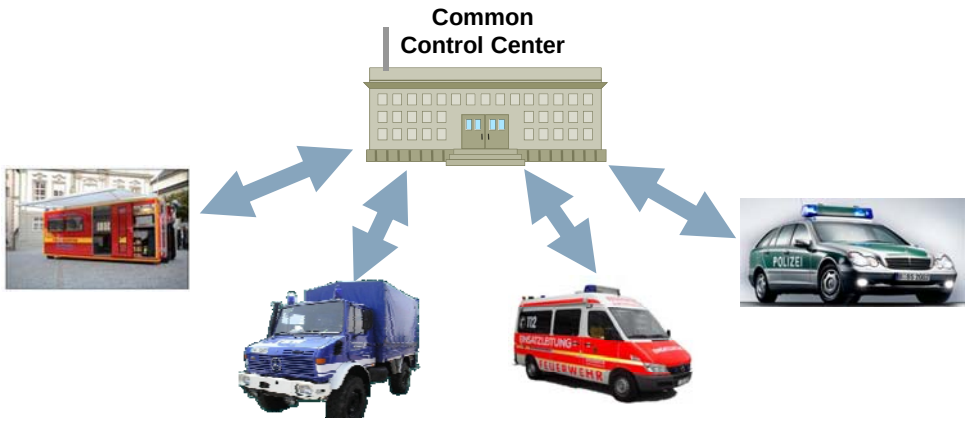

Figure 4-15: Scenario C1 Example „Common control center“

4.3.2 Scenario C2: Data transmission from the on-site operational forces to the control center / headquarters

In this scenario the main issue is the data transmission from the operation scene to the control center or headquarters. So the main data traffic is transmitted via the uplink (cp. chapter 4.1.2).

In contrast to scenario A2 here the general and additional conditions related to a natural or major disaster are given (see above). Thus, there are several more applications and services possible in addition to the ones mentioned in chapter 4.1.2.

One possible example is the communication of sensors (temperature, gas, radiation, etc.) with the control center or headquarters to achieve a better assessment of the situation at the operating scene. The usage of sensor data is also interesting for regular operations but especially important in the case of a major disaster. Because one the hand due to the geographical dimension the assessment of the scale of the disaster is complicated without distributed sensors and on the other hand due to the disaster physical access to certain areas is often not possible (buildings, tunnels, etc.)

The sensors can either be pre-installed (e.g. in tunnels) or installed and activated by the operational forces during the operation. Also the dropping of sensors from an airplane or a helicopter is thinkable. Especially if the operational forces installs and operates the sensors a wireless connection between the sensors is necessary for this ad hoc installation. For this purpose wireless technologies and standards are already existing, e.g. Zigbee or WLAN.

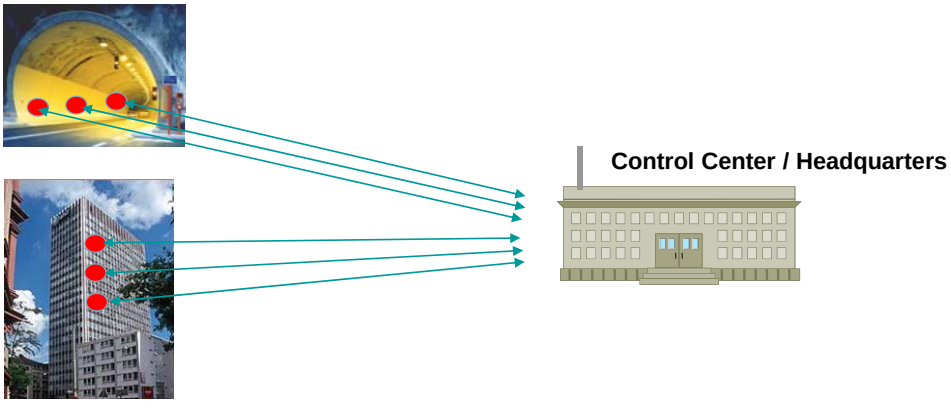

Figure 4-16: Scenario C2 Example „Data connection of sensors with the control center“

During operation the connected sensors periodically transmit measurement data into the headquarters. Often these measurement data are already pre-evaluated and summed at the operation scene to reduce the data load in the headquarters.

4.3.3 Scenario C3: Communication between vehicles and operational spots at the operation scene

In this scenario the main issue is the communication between multiple vehicles or operational spots at the operation scene (cp. chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**).

In contrast to scenario A3 here the general and additional conditions related to a natural and major disaster are given (see above). Thus there are several more applications and services possible in addition to the ones mentioned in chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**.

One example is the usage of connected robots in areas that are destroyed by the disaster and thus not accessible anymore, e.g. if buildings are extremely in danger of collapsing or areas are contaminated by radiation as consequence of a nuclear incident.

The robots have to be connected with the control center to be able to transmit reconnaissance data. Furthermore, in some operations the inter-connection between the robots can be helpful for instance to establish a communication link over large ranges between the control center and the operation scene by the usage of mobile relays (see **Fehler! Verweisquelle konnte nicht gefunden werden.**).

E.g. a robot equipped with special laser cameras can be used for digital 3-dimensional measuring of buildings that are in danger of collapsing. With them also a minimum motion of parts of the building can be detected. Thus, an alerting can follow up in sufficient time before the collapse. Temperature, gas, and radiation sensors can support to evaluate the scale of the disaster and to take appropriate countermeasures.

Besides the communication the connection between the control center and the robots can also to be used to control the robots and accordingly to control their integrated sensors. E.g. the robots could also be equipped with a controllable manipulator arm to open doors or to remove obstacles. Examples of controlling the sensors of the robotics are the control of an integrated PTZ camera or the configuration of a sensor board.

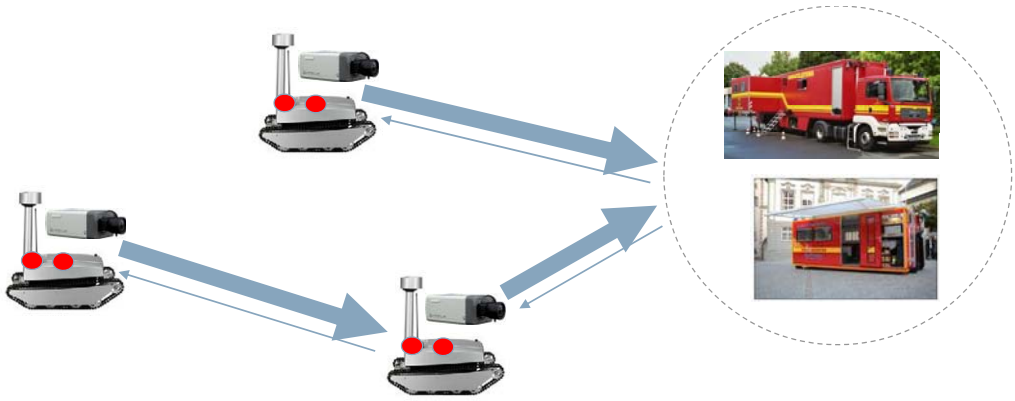

Figure 4-17: Scenario C3 Example „Usage of robotics“

To be able to steer the robot the operational forces need video information from the view of the robot. These video pictures have to be transmitted from cameras installed on the robot to the operational forces.

4.3.4 Scenario C4: Communication between individuals at the operation scene

In this scenario the main issue is the communication between individuals, e.g. individual policemen, fire fighters, or medics that are not assigned to special operating resources (vehicles). Thus, each person has to carry an own communication device (cp. chapter 4.1.4).

In contrast to scenario A4 here the general and additional conditions related to a natural or major disaster are given (see above). E.g. in such scenarios the number and concentration of the operational forces normally is higher than during normal operations. Also the communication between individuals of different PPDR agencies is a possible application scenario, e.g. the operation coordination by voice or by exchange of messages. As mentioned above in the case of a disaster pre-installed communication infrastructures are often destroyed (e.g. base stations) and thus cannot be used for the communication anymore.

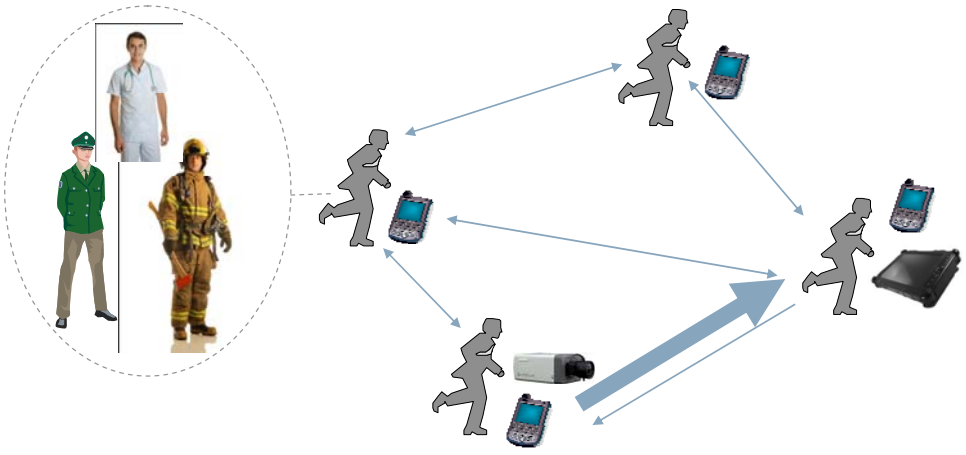

Figure 4-18: Scenario C4: Communication between individuals at the operation scene

4.3.5 Scenario C5: Operation in tunnels / buildings / cellars

This communication scenario considers the data transmission between communication partners that can be inside tunnels, buildings, or cellars. In such an environment the wireless communication is affected e.g. by the construction of the building (walls, ceilings) that results in an attenuation of the wireless signal.

Inside the buildings mainly individual persons act as communication partners. Whereas, in the outside persons, vehicles, temporary on-site control centers or remote control centers participate the communication.

In contrast to scenario A5 here the general and additional conditions related to a natural or major disaster are given (see above). For instance, specific communication infrastructure in buildings designed and installed for the in-house radio coverage (e.g. repeaters) could be destroyed by the disaster.

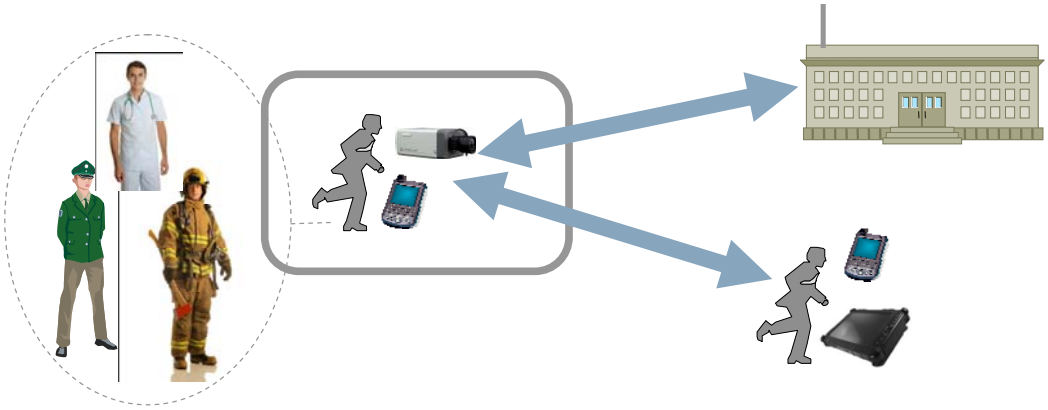

Figure 4-19: Scenario C5: Operation in tunnels / buildings / cellars

4.3.6 Scenario C6: Access to information from the internet and accordingly communication with external partners

In this scenario the main issue is the access to networks that are not owned or operated by the PPDR agencies (e.g. the internet) or the communication with external consultants or institutes directly with the on-site operational forces. This scenario does not consider the case that the communication is established first to the control center or headquarters and then from there to the external networks or persons. Because in this case the wireless communication is mainly from the operation scene to the control center / headquarters (cp. scenario B2 and B3). Generally, the data will then be forwarded from there into the internet by wire.

As described in scenario A6 the main challenge here is the data security because generally civilian communication networks are not operated by the PPDR agencies.

In contrast to scenario A6 here the general and additional conditions related to a natural or major disaster are given (see above).

Infrastructure is often destroyed during natural disasters. Of course, also the communication infrastructure is affected. Base stations could be destroyed or disconnected from the power line. As a consequence an own self-sufficient communication infrastructure has to be brought into operation on-site. This infrastructure should allow the involvement of external parties. Thus, a connection of the different PPDR agencies with external networks (e.g. internet) is necessary.

For rescue operations after natural disasters equipment and skills are required that are often not available at the PPDR agencies. The request of additional resources requires communication with external parties.

Due to the often large geographical dimension of a natural disaster it is absolutely necessary for the planning and coordination of rescue operations to permanently get an overview about the requested and deployed resources. Thus, a continuous communication between the control center and the resources is necessary.

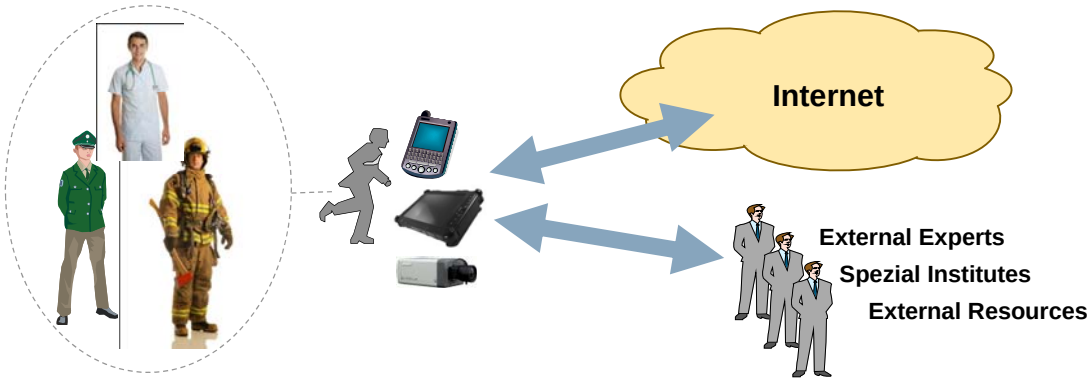

Figure 4-20: Scenario C6: Access to information from the internet and accordingly communication with external partners

5 Results of the interviews

This chapter provides a summary of the fundamental results that were obtained from the interviews. More detailed results can be found on the questionnaires that were filled out during the interviews in cooperation with the interviewees.

5.1 Interview partner 1: Federal Office for Goods Transport (BAG)[1]

5.1.1 Scenario 1.1: Broadband access for mobile inspectors

This scenario requires broadband access for mobile inspectors to the headquarters or the internet. Use cases are the entry of case details (case entry software KOWIKA, images, data, etc.), voice communication (including external calls), help desk and access to the Internet (hazardous materials databases, queries to detect illicit work). Beyond this it is intended to connect weigh stations with the mobile inspection teams (real-time video transmission) over a central server. The inspectors can be indoors for voice communication. This scenario is only relevant for the category A, starting *immediately*. As a result the communications scenarios A1, A2, A5, and A6 apply.

This scenario requires a network with nationwide coverage. The system currently uses the Public Land Mobile Network. In the medium term it requires a data rate of 4Mbit/s on-site. The communication links should be full-duplex and reliable for speeds up to 100km/h.

This service is classified *important*. It must provide blanket coverage (largely outside metropolitan areas) and be highly available in terms of time. The network delay must be short. The data must be protected against interception and be encrypted.

Initial evaluation

Scenario 1.1 can be met with a Public Land Mobile Network, assuming that blanket coverage with HSDPA/HSUPA technologies that provide the required bandwidth will be available in the medium term. Because of the involvement of a central server the communication between inspection teams and weigh stations cannot currently use an ad hoc communication technology in the GHz band.

5.2 Interview partner 2: Bavarian Mountain Rescue Service

5.2.1 Scenario 2.1: Voice communication

This scenario describes the voice communication between control center and operation scene and between on-site operational forces (personnel, vehicles, and helicopter). It is important to note that the forces (personnel and vehicles) are often called into thinly populated mountain and border regions. The voice communication must be powerful and provide blanket coverage. The

[1] The German Federal Office for Goods Transport is an independent higher federal authority in the portfolio of the Federal Ministry of Transport, Building and Urban Development. It is headquartered in Cologne.

Mountain Rescue Service estimates that the TETRA system will not be available in remote areas in the immediate future.

As a temporary stopgap measure five analog Single-frequency networks (SFN) are planned to complement the TETRA network. The communication between personnel that uses both, TETRA and SFN, must be guaranteed. The change-over between the two technologies must work seamlessly. Additionally, the communication with a helicopter must be possible. This scenario relates to all three categories (A, B, and C) starting *immediately*. The resulting communications scenarios are A1 – A4, B1 – B4, and C1 – C4.

This scenario requires blanket radio coverage of Bavaria, including thinly populated mountain and border regions. It requires 19 voice channels with a data rate of 64kbit/s per channel. Half duplex links are sufficient. The communication partners are mobile with a speed of up to 250km/h.

This service is classified as *mission critical*. It must provide blanket coverage (including thinly populated mountain regions) and high availability in terms of time. The call setup must be immediately and the signal delay must be short. The data must be protected against manipulation.

Initial evaluation

Scenario 2.1 can be realized with the already planned 5 analog Single-Frequency network systems.

5.2.2 Scenario 2.2: Alerting through Single-Frequency Network (SFN)

This scenario describes the alerting by the rescue control center. The personnel to be alerted can be indoors. This can be achieved by the Single-Frequency Network, for instance in the 4-metre (70 MHz) band. It is important, that the alert can be reliably transmitted into exposed areas. This scenario is relevant for all categories (A, B, and C) starting *immediately*. The resulting communications scenarios are A1, A2, A5, B1, B2, B5, C1, C2, and C5.

This scenario requires blanket radio coverage of Bavaria where the range to the rescue control centre can be up to 100km. The required data rate is only a few kbit/s, but the communication system must support broadcast/multicast addressing and encoding. The link can be unidirectional, because an acknowledgment is not required. The communication partners are mobile with the speed of a motor vehicle.

This service is classified as *mission critical*. It must provide blanket radio coverage (including thinly populated mountain regions) and high availability in terms of time. The call setup must be immediately and the signal delay must be short. The data must be protected against manipulation.

Initial evaluation

Scenario 2.2 can be realized with the already planned 5 analog Single-Frequency network systems.

5.2.3 Scenario 2.3: Deployment of Unmanned Aerial Vehicles (UAV) for Reconnaissance

This scenario requires a data connection between the UAV and the rescue vehicle (e.g. the pilot) to send control commands to the UAV and to receive video, thermal imaging, and positioning information from the UAV. This scenario is relevant for all categories (A, B, and C) starting *immediately*. The resulting communications scenarios are A3, B3, and C3.

This scenario requires radio coverage at the operation scene with a maximum radius of 15km. The scenario is limited to a single UAV at the operation scene. The required data rate from the UAV to the control station is up to 1Mbit/s, in the opposite direction a few kbit/s are enough. The scenario requires a full-duplex link that works reliable for a speed of the UAV up to 50km/h.

This service is classified as *mission critical*. It must provide blanket coverage (including thinly populated mountain regions) and high availability in terms of time. The call setup and the signal delay must be short. The data must be protected against manipulation.

Initial evaluation

Normally Scenario 2.3 would be a typical application scenario for wireless ad hoc technology in the GHz band. However, on this base the range of up to 15km is difficult to bridge. The continuous movement of the UAV makes the use of directional antennas difficult.

As an alternative solution this scenario might necessitate the deployment of a new network with blanket radio coverage, which meets the requirements (mission critical, high availability, bandwidth of up to 1Mbit/s).

5.2.4 Scenario 2.4: Redundant radio connections for mountain huts, repeaters and emergency call systems to a network

To provide redundancy this scenario requires an additional radio connection for mountain huts, repeaters and emergency call systems to a network (for instance the internet). This scenario is relevant for all categories (A, B, and C) starting *immediately*. It is a new scenario: the connection of mountain huts, repeaters and emergency call systems to a network.

This scenario requires point-to-point links that cover ranges of up to 15km. The required data rate is 1Mbit/s per link, limited to one link per hut or station. The link must be full-duplex, the communication endpoints are stationary.

This service is classified as *important* to *mission critical*. It must be available at the locations of the mountain huts or stations and must be highly available in terms of time. The links are dedicated and hence do not require a connection setup. The signal delay must be short. Health records are sensitive and must be encrypted.

Initial evaluation

Scenario 2.4 can be realized with a point-to-point communication technology like microwave transmission or satellite. Every link must provide full-duplex transmission at a data rate of 1Mbit/s.

5.3 Interview partner 3: Municipal Fire Brigade Berlin

5.3.1 Scenario 3.1: Communication at the operation scene

Scenario 3.1 requires communication coverage at the operation scene. Relevant applications are telemetry (environment sensors (temperature, etc.), monitoring of vital signs and equipment (breathing apparatus), location data, etc.), transmission of still or live images (for instance from a thermal imaging camera) from the operational spot to the command vehicle, and other applications of the rescue service. The communication takes place between vehicles and response locations or between personnel where the latter may be inside of buildings (for instance for telemetry). This scenario is *immediately* relevant for categories A and C. It is relevant *in the medium term* for category B, where the applications of the rescue service have the highest priority. The resulting communications scenarios are A3 – A5, B3 – B5, and C3 – C5.

This scenario requires radio coverage of the operation scene, where the category A area has a radius of a few 100m, the category B area of a few km and the category C area of a few 100km. The required data rate per response location is 4Mbit/s for category A, 2Mbit/s for category B and at least 10Mbit/s for category C. The links must be full-duplex. The communication partners are mobile (walking speed).

This service is classified *mission critical* for categories A and C and *important* for category B. It must provide blanket coverage and be highly available in terms of time. The connection setup time and the network delay must be short. The data are sensitive and must hence be encrypted.

Initial evaluation

An ad hoc technology in the GHz band (for instance 5.15 – 5.25GHz) can be used to provide radio coverage of the operation scene in scenario 3.1 (video transmission and applications of the rescue service). However, this technology cannot directly cover the long ranges (radius a few 100km) in the operation scene of category C. To overcome this limitation one could cluster the network nodes of each operational section and then connect the clusters by microwave transmission or satellite.

Alternatively, a new network with blanket coverage in Berlin would need to be installed, that meets the requirements (data rate of up to 10MBit/s, high availability, mission critical). A technology operating in a low frequency range (lower MHz band) would be needed to support the telemetry applications inside of buildings.

5.3.2 Scenario 3.2: Alerting and Dispatching

Scenario 3.2 covers the alerting and dispatching of the operational forces. The alerting is realized through paging (including active paging with acknowledgement). The dispatching is done through the acquisition of the current location of all vehicles. Communication takes place between the control center and the alerted operational forces / resources. This scenario relates to all three categories (A, B, and C) starting *immediately*. The applicable communications scenarios are A1, A2, B1, B2, C1, and C2.

This scenario requires blanket radio coverage of Berlin including the outskirts (area of about 300km^2). The required downlink data rate is limited to a few 10kbit/s while the uplink data rate can be as low as a few 100kbit/s in category A and B and a few Mbit/s in category C (because of the acknowledgements in active paging). It is sufficient if the links are half duplex. The communication partners are mobile with a speed of up to 100km/h.

This service is classified as *mission critical*. It must provide blanket radio coverage and high availability in terms of time. The call setup must be very short and the signal delay must be short. Usually, the data are not sensitive (except for paging of the rescues service). But the data and the service must be protected against unauthorized access.

Initial evaluation

Scenario 2.3 requires a network with blanket coverage that meets the requirements (mission critical and high availability). The nominal data rates are per operation scene. The individual links require much lower data rates so that it could be implemented on top of the TETRA system. This requires that TETRA meets the requirements regarding coverage and availability.

5.3.3 Scenario 3.3: Control of traffic guidance systems to optimize access routes

This scenario entails the direct communication between operation vehicles and smart traffic infrastructure. The purpose is to control traffic guidance systems so that the operation forces are mobile as fast and direct as possible even in congested city traffic. This scenario relates to all three categories (A, B and C) starting *immediately*. The communication between operational vehicles and traffic guidance systems is a new communication scenario.

The operational forces need to be able to take control of a traffic control center from a maximum range of 1000m. This requires coverage centered at the traffic control center with a maximum radius of 1000m. The required data rate is about a few 100kbit/s per traffic control center. Half duplex links are sufficient. The vehicles move with a speed of up to 70km/h.

This service is classified *important* in categories A and B. It is classified *desirable* in category C. It must provide blanket coverage and be timely available. A short connection setup time is required. The data are not sensitive, but the service must be protected against unauthorized access.

Initial evaluation

IEEE 802.11p is a new standardized technology for the communication between vehicles and traffic guidance systems (scenario 3.3). It utilizes the frequency band from 5.85 up to 5.925GHz and could be used to realize scenario 3.

5.3.4 Scenario 3.4: Transmission of medical records to the hospital

This scenario deals with the transmission of medical records from the rescue vehicles (either at the operation scene or in transit to the hospital). External experts can be consulted over voice and video. This scenario is relevant in all three categories (A, B, and C) starting *immediately*. Because the hospital and the external experts are external sources, the communication scenarios A6, B6, and C6 apply.

This scenario requires blanket radio coverage of Berlin including the outskirts (area of about 300km^2). The transmission of the medical records requires a data rate of a few 10kbit/s. The transmission of videos requires an uplink data rate of 1Mbit/s per rescue vehicle. Category A requires up to 10, categories B and C require at least 50 simultaneous connections. The links must be full-duplex; the assets are mobile with a speed of up to 100km/h.

The service is classified as *important*. It must provide blanket coverage and be timely available. A short connection setup time is required. The data are sensitive and require encryption.

Initial evaluation

Scenario 3.4 can be implemented on top of the Public Land Mobile Network. This depends on the HSUPA technology upgrade of the existing network with the required coverage and availability.

5.3.5 Scenario 3.5: Information transmission from the control center to operational resources additionally to the alerting

This scenario envisions the transmission of additional information beyond the alerting from the control center to the operational resources. This scenario is *immediately* relevant for categories A and C and in the *medium term* for category B. The applicable scenarios are A1, B1, and C1.

This scenario requires blanket radio coverage of Berlin including the outskirts (area of about 300km^2). The required data rate per link is 100kbit/s. It has to be considered that Category A needs up to 10 simultaneous connections, category B up to 3 simultaneous connections, and category C up to 20 simultaneous connections. Semi duplex links are sufficient. The operational resources are mobile with a maximum speed of 100km/h.

The service is classified *important*. It must provide blanket coverage and be timely available. A short connection setup time is required. Usually the data are not sensitive, but must be protected against manipulation.

Initial evaluation

Scenario 3.5 can be implemented on top of a Public Land Mobile Network.

5.3.6 Scenario 3.6: Access to external and internal data bases

This scenario gives the operational forces at the operation scene access to data bases at the control center and the internet. This scenario is *immediately* relevant for categories A and C and in the *medium term* for category B. The applicable scenarios are A1, A2, A6, B1, B2, B6, C1, C2, and C6.

This scenario requires blanket radio coverage of Berlin including the outskirts (area of about 300km^2). The required data rate is 2Mbit/s for the downlink and a few kbit/s for the uplink. Categories A and B require only one link, category C up to 3 simultaneous links in the operation scene. The links must be full-duplex. The communication partners are stationary when they access the service.

The service is classified as *important*. It must provide blanket coverage and be timely available. A short connection setup time is required. Usually the data are not sensitive, but must be protected against manipulation.

Initial evaluation

Scenario 3.6 can be implemented on top of the Public Land Mobile Network. This depends on the HSDPA technology upgrade of the existing network with the required coverage and availability. Alternatively this scenario could be implemented based on satellite communication. This has the additional advantage (especially for category C) that it is independent of existing infrastructure.

5.3.7 Scenario 3.7: Data exchange between NBC reconnaissance vehicles

In this scenario data exchange takes place between NBC reconnaissance vehicles at the operation scene. This scenario applies in the *medium term* to category A and *immediately* to category C. The applicable scenarios are A3 and C3.

This scenario requires blanket radio coverage of Berlin including the outskirts (area of about 300km^2). The required data rate is 1Mbit/s per link. Category A requires up to 3 simultaneous links and category C requires up to 12 simultaneous links. The links must be full-duplex. The communication partners are mobile with a speed of up to 50km/h.

The service is classified as *important*. It must provide blanket coverage and be timely available. A short connection setup time is required. The data are not sensitive, but must be protected against manipulation.

Initial evaluation

Scenario 3.7 would be a typical usage scenario for ad hoc technology in the GHz band. However, this technology is only applicable for smaller incident areas. It would not be able to cover the ranges if the operation scene in fact covers all of Berlin. In this case the scenario could be implemented on top of the Public Land Mobile Network. This requires the HSUPA technology upgrade of the existing network with the required coverage and availability.

5.3.8 Scenario 3.8: Infrastructure to connect the operation scene with the control center

This scenario postulates that in case of a natural or other major disaster a radio connection between the operation scene and the control center or an access point into a network (including external networks) gets established. Applications are transmission of status reports (for instance refueling reports of emergency power generators) or voice (for instance connecting a mobile TETRA base station to the access point). This scenario applies to category C in the *medium term*. Hence the applicable scenarios are C1, C2, and C6.

This scenario requires a point-to-point link between the operation scene and the control center or the network access point. The range to cover is up to 50km. The required data rate for voice communication (for instance to connect a mobile TETRA base station) is 2Mbit/s per link with up to 5 simultaneous links. The status reports require a few 10kbit/s with up to 50 simultaneous links. The links are required to provide full-duplex communication. The communication partners are stationary.

The service is classified as *mission critical* for the voice communication and *important* for the status reports. It must provide blanket coverage and high availability in terms of time (especially for the voice communication). A short connection setup time is required. The data are not sensitive, but must be protected against manipulation. The connection setup time and the signal delay must be short.

The data must be protected against manipulation. Additionally, the voice data are sensitive and must be encrypted.

Initial evaluation

Scenario 3.8 requires point-to-point links. These could be realized either by microwave transmission or satellite technology.

5.4 Interview partner 4: Municipal Fire Brigade Dortmund

5.4.1 Scenario 4.1: Situation reconnaissance und situation reporting

This scenario is focused on situation reconnaissance and situation reporting. Situation data are normal or thermal images, videos, audio data, and electronic maps. The images can originate from cameras in UAV and helicopters or from fixed pre-installed cameras. The communication is either local at the operation scene or with the control center. The situation reporting can also go from the control center to the operational forces (for instance on the way to the operation scene). The transmission of positioning information (for instance for heliports or drop zones etc.) and audio broadcasts for situation reporting is planned alongside the image data. The operational forces communicate with the control center; data are exchanged between vehicles (including UAV and helicopters) and the operation scene and among the personnel on-site. This scenario relates to all three categories (A, B, and C) starting *immediately*. The resulting communications scenarios are A1 – A4, B1 – B4, and C1 – C4.

This scenario requires blanket coverage. The operation scene for category A has a radius of a few 100m and in categories B and C of several kilometers. The maximum distance to the control center is up to 100km for all categories. The required data rate for category A is 8Mbit/s per operation scene. The data rate for category B and C can be significantly larger than during normal operations. An exact number can currently not be specified. The EU project “Share” assumes rough approximation of 256Mbit/s at the operation scene but the data rate for smaller operational sections can be lower. The links must be full-duplex. Control vehicles are stationary when accessing the service, helicopters and UAV are mobile with a speed of up to 200km/h.

This service is classified as *mission critical*. The service must provide blanket coverage for the basic functionality (audio, reports) and high availability in terms of time. Control vehicles can be positioned on strategic locations to improve the link quality. The connection setup time and the signal delay can be in the realm of a few seconds. The data must be protected against manipulation.

Initial evaluation

An ad hoc technology in the GHz band can be used to cover the operation scene in scenario 4.1. Longer ranges can be covered by using multiple relays. Alternatively, the data of a section is bundled at a single station. These stations are then connected either by microwave transmission or satellite.

Stationary control vehicles can be connected to the control center either by microwave transmission or satellite. Data from mobile vehicles (helicopter or UAV) are locally transmitted to the control vehicle that then relays the data to the control center via microwave transmission or satellite.

5.4.2 Scenario 4.2: Transmission of status reports

This scenario requires the transmission of status reports (numerical codes including sub codes) from the head of operations to the control center or from vehicles and operational spots at the operation scene to the local commander. This scenario relates to all three categories (A, B, and C) starting *immediately*. The resulting communications scenarios are A2, A3, B2, B3, C2, and C3.

This scenario requires the radio coverage of the operation scene. The operation scene of category A has a radius of a few 100m and of category B and C of multiple kilometers. The

maximum range to the control center is up to 100km for all categories. The required data rate per operation scene is 1kbit/s for category A. The required data rate in category B and C is 1kbit/s per link with up to a multiple of 100 simultaneous links. Semi duplex links are sufficient and the communication partners are mobile with a speed of up to 60km/h.

This service is classified as *important*. The service must provide coverage of the operation scene. Vehicles can be positioned at strategic locations to improve the link quality. Small signaling delays are acceptable. Both, the connection setup time and the signal delay can be in the realm of a few seconds. The data must be protected against manipulation.

Initial evaluation

Scenario 4.2 can be implemented on top of either the Public Land Mobile Network or alternatively TETRA. Important is the availability of a multiple 100 simultaneous links in the operation scene.

5.4.3 Scenario 4.3: Sensor data at the operation scene

This scenario requires connectivity for sensors at the operation scene. The sensors in question are a thermal camera, vital signs and telemetry data of breathing apparatus. The sensor data are transmitted to either a control vehicle or an on-site station. This means that the communication takes place between individual persons (can be indoors) and vehicles and response locations. This scenario relates to all three categories (A, B, and C) starting *immediately*. The resulting communications scenarios are A3 – A5, B3 – B5, and C3 - C5.

This scenario requires the radio coverage of the operation scene. The radius in category A is up to 50m, in category B up to 500m and in category C up to 1000m. The required data rate for category A is 5Mbit/s, for category B 9Mbit/s and for category C 11Mbit/s per operation scene or operation section. The links must be full-duplex. Communication partners are mobile with walking speed.

The telemetry is classified as *mission critical*, the remainder as *important*. The service must provide blanket coverage and high availability (especially for telemetry). The connection setup time and the signal delay must be short. The data must be protected against manipulation.

Initial evaluation

The outdoor connectivity and the video application can be implemented on top of an ad hoc technology in the GHz band. A technology based on lower frequencies (e.g. the lower MHz band) should be used for the sensor data inside of buildings (e.g. the monitoring of the breathing apparatus).

5.4.4 Scenario 4.4: Access to data services in the control center or the internet

This scenario requires access to data services provided either at the control center (e.g. area maps, site plans of premises, or detailed object information) or the internet (e.g. rescue cards for cars, hazardous material information systems or incident procedure manuals) directly from the operation scene. This scenario relates to all three categories (A, B, and C) starting *immediately*. The resulting communications scenarios are A1, A2, A6, B1, B2, B6, C1, C2, and C6.

This scenario requires the radio coverage of the operation scene. The radius in category A is multiple 100m and in categories B and C multiple kilometers. The maximum distance to the control center is up to 100km in all categories. The required data rate is 10Mbit/s per control

vehicle. In category A there is one control vehicle at the operation scene, in category B up to 10 and in category C up to 20 control vehicles. The links must be full-duplex. The communication stations are stationary.

The service is classified as *important*. It requires blanket coverage. The control vehicles can be placed to optimize the link quality. Short delays for connection setup and network delay are acceptable. The data are sensitive and require encryption (e.g. medical records from a patient database).

Initial evaluation

The communication partners are stationary. This allows the implementation of scenario 4.4 on top of satellite communication solution. Alternatively a Public Land Mobile Network could be used. However, the currently deployed PLMNs do not support the required data rates (up to 10MBit/s per link).

5.5 Interview partner 5: unspecified

Because of the sensitive nature of the information provided by this interviewee, a summary cannot be included in this report. The full results are recorded in the questionnaire and were considered for the overall conclusion.

5.6 Interview partner 7: Federal Police (BPOL)

Generally the Federal Police plans to use external networks for the scenarios 7.4 to 7.8 for abroad operations. Using satellite based communication is the preferred solution because of its independence from local infrastructure.

5.6.1 Scenario 7.1: Connectivity between different coordination centers

Due to redundancy reasons, in this scenario stationary control centers (about 130 in Germany) will be connected to two central servers. Additionally, mobile control centers shall be connected with the stationary control centers. The control centers can belong to different PPDR agencies. This scenario is relevant for all categories (A, B, and C) starting *immediately*. Because the mobile control centers are at the operation scene, the applicable communications scenarios are A1, A2, B1, B2, C1, and C2. Additionally, the connection between the stationary control centers and the central servers constitutes a new communication scenario.

The connection of the control centers requires point-to-point links. Normally, the control centers (mobile and stationary) are located inside Germany, but a deployment abroad or even at sea is possible, too. Immediately, the required bandwidth is 2Mbit/s, the medium term requirement is unspecified. In Germany are 130 stationary coordination centers. Additionally, up to 3 mobile coordination centers can be deployed at an operation scene. The links must be full-duplex and the communication partners can be mobile.

The service is classified as *mission critical*. It must provide blanket coverage and be highly available in terms of time. The connection setup time must be short (a few seconds) and the signal delay must be less than 0.5s (RTT). The data are sensitive (VS-NfD/Restricted) and must be encrypted.

Initial evaluation

The connectivity for the 130 stationary coordination centers can be realized by satellite technology. Mobile abroad control centers require a satellite based technology as well. The mobility support makes achieving the required data rate challenging.

A new dedicated network with blanket coverage is required to connect the mobile command centers inside Germany, because currently installed networks do not meet the stated requirements (high data rate of 3x2Mbit/s, mission critical, high availability).

5.6.2 Scenario 7.2: Connecting vehicles and fixed cameras to mobile and stationary coordination centers

This scenario requires that vehicles and fixed installed cameras are to be connected to mobile or stationary control centers / command posts. The primary applications will be data transmission (access to data bases, entry and check of finger prints, situation reports, etc.) and video transmission from fixed cameras. This scenario is relevant for all categories (A, B, and C) starting immediately. Because the cameras can be installed inside of buildings the applicable communications scenarios are A1, A2, A5, B1, B2, B5, C1, C2, and C5.

This scenario requires blanket coverage inside Germany but also abroad and at sea. The required bandwidth and the number of simultaneous links cannot be specified. The communication links should be full-duplex and the communication partners can also be mobile.

The service is classified as *mission critical*. It must provide blanket coverage in Germany and be highly available in terms of time. The connection setup time must be short (in the range of seconds) and the signal delay must be less than 0.5s (RTT). The data are sensitive (VS-NfD/Restricted) and must be encrypted.

Initial evaluation

In Germany scenario 7.2 requires a new network with blanket coverage because the existing networks cannot meet the requirements (mission critical, high availability). Abroad and at sea a satellite technology can be used.

5.6.3 Scenario 7.3: Voice communication as complement/redundancy for TETRA

The application in this scenario is radio based voice communication as complement or redundancy for TETRA. The communication partners can be individual persons, vehicles (including helicopters and Unmanned Aerial Systems), the control center or external partners. The personnel can be inside buildings. This scenario is relevant for all categories (A, B, and C) starting *immediately*. Hence, the applicable communications scenarios are A1–A6, B1–B6, and C1–C6.

This scenario requires blanket radio coverage in Germany including the exclusive economic zone in the North and the Baltic Sea and also abroad (on demand). The maximum distance to the control center (in Germany) can be up to 300km. The data rate must be high enough to provide the same quality as ISDN (64kbit/s). The number of simultaneous connections at the operation scene cannot be specified. The communication links should be full-duplex and reliable for speeds up to 300km/h (helicopter).

This service is classified as *mission critical*. If the service is based on third party or civilian networks, it must have priority access. It must provide blanket coverage and be highly available in terms of time. The call setup time must be short and the speech must be easily

understandable. The data are highly sensitive and must be encrypted. Unauthorized interception and access by third parties (eventually even by other PPDR agencies) must be prevented.

Initial evaluation

Scenario 7.3 requires a new network with blanket coverage because the current networks cannot meet the requirements (mission critical, high availability, priority access). A special challenge is the connectivity to helicopter and UAV that might fly at high altitudes. Abroad and at sea this scenario can be realized based on satellite technology.

5.6.4 Scenario 7.4: Data communication between personnel, vehicles, and control center

This scenario realizes the data transmission (geographical data including maps, location information, status reports etc.) between personnel, vehicles (including helicopter, UAV and train), and the control center. The personnel might be inside buildings. This scenario is relevant for all categories (A, B, and C) in the *medium term* (e.g. within 5 years). Hence, the applicable communications scenarios are A1 – A5, B1 – B5 and C1 – C5.

This scenario requires blanket radio coverage in Germany including the exclusive economic zone in the North and the Baltic Sea and also abroad (on demand). The maximum distance to the control center (in Germany) can be up to 300km. The required data rate is 1-2Mbit/s. The number of simultaneous connections at the operation scene cannot be specified. The communication links should be full-duplex and reliable for speeds up to 300km/h (helicopter, train).

The service is classified as *mission critical*. If the service relies on third party or civilian networks, it must have priority access. It must provide blanket coverage and be highly available in terms of time. The connection setup time must be very short. The data are sensitive and must be encrypted. Unauthorized interception and access by third parties (eventually even by other PPDR agencies) must be prevented. The data integrity must be protected and documented (might be used as evidence in a court of law).

Initial evaluation

Inside Germany scenario 7.4 requires a new network with blanket coverage because the current networks cannot meet the requirements (mission critical, high availability, priority access). A special challenge is the connectivity to helicopter and UAV that might fly in high altitude. Abroad and at sea this scenario can be realized based on satellite technology but the data rate is very high for portable devices.

5.6.5 Scenario 7.5: Video and image transmission, video conferencing

This scenario requires the transmission of videos and images between personnel, vehicles (including airborne vehicles and trains), and command centers. The personnel can be indoors. Additionally, video conferencing that might include third parties shall be possible. This scenario is relevant for all categories (A, B, and C) starting *immediately*. Hence, the applicable communications scenarios are A1 - A6, B1 – B6 and C1 - C6.

This scenario requires blanket radio coverage in Germany including the exclusive economic zone in the North and the Baltic Sea and abroad (on demand). The maximum distance to the control center (in Germany) can be up to 300km. The scenario requires the transmission of high

resolution images with a low frame rate (5-10 fps). For this a data rate of 2Mbit/s should be enough. Up to 5 simultaneous video transmissions are required. The video conferencing requires a data rate of 2Mbit/s with up to 10 participants per operation scene. The communication links should be full-duplex and support mobile communication partners that move with a speed of up to 300km/h (helicopter, high speed train).

The service is classified as *important*. If the service relies on third party or civilian networks, it must have priority access. It must provide blanket coverage and be highly available in terms of time. Service activation and connection setup time must be short. The data are sensitive and must be encrypted. Unauthorized interception and access by third parties (eventually even by other PPDR agencies) must be prevented. The data integrity must be protected and documented (might be used as evidence in a court of law).

Initial evaluation

Inside Germany scenario 7.5 requires a new network with blanket coverage because the current networks cannot meet the requirements (data rates 5x2Mbit/s + 10x2MBit/s, high availability, priority access). Abroad s and at sea this scenario can be based on satellite technology but the data rate is very high for portable devices. Multicast capability of the network would reduce the data rate required for video conferencing.

5.6.6 Scenario 7.6: Intranet and internet access

This scenario requires that command centers (personnel or vehicle incl. aerial vehicles and trains) can access services in the intranet or internet. The personnel might be inside of buildings. This scenario is relevant for all categories (A, B, and C) starting *immediately*. Hence, the applicable communications scenarios are A1, A2, A5, A6, B1, B2, B5, B6, C1, C2, C5, and C6.

This scenario requires blanket radio coverage in Germany including the exclusive economic zone in the North and the Baltic Sea and also abroad (on demand). The maximum distance to the control center (in Germany) can be up to 300km. The scenario requires a data rate from the set of standardized WLAN-802.11a/g rates (e.g. 10MBit/s) per command center. In category A there might be 1 or 2 command centers and in categories B and C up to 5 - 10. The communication links should be full-duplex and support mobile communication partners that move with a speed of up to 300km/h (helicopter, high speed train).

The service is classified as *important* in category B and otherwise as *desirable*. If the service relies on third party or civilian networks, it must have priority access. It must provide blanket coverage and be highly available in terms of time. Service activation and connection setup time must be short. The data are sensitive and must be encrypted. Unauthorized interception and access by third parties (eventually even by other PPDR agencies) must be prevented.

Initial evaluation

Inside Germany scenario 7.6 requires a new network with blanket coverage because the current networks cannot meet the requirements (data rates 10MBit/s per link, high availability, priority access). Abroad and at sea this scenario can be realized based on satellite technology. However, the data rate is very high for portable devices.

5.6.7 Scenario 7.7: Radio direction finding

In the radio direction finding scenario a person or vehicle is equipped with a radio transmitter. The receiver is carried by a person or a vehicle (including aerial vehicles and trains) up to 15km away or at the head quarter. The devices might be also inside buildings. This scenario is relevant for categories A and B starting *immediately*. Hence, the applicable communications scenarios are A2, A5, B2 and B5.

This scenario requires radio coverage that bridges up to 15km between transmitter and receiver in Germany including the exclusive economic zone in the North and the Baltic Sea and also abroad (on demand). The required data rate is about 50kBit/s with up to 5 simultaneous connections per operation scene. Unidirectional communication links are sufficient. The communication partners are mobile with a speed of up to 300km/h (helicopter, high speed train).

The service is classified as *mission critical*. It must provide blanket coverage and be highly available in terms of time. Service activation and connection setup time must be very short. Unauthorized interception and access by third parties (eventually even by other PPDR agencies) must be prevented. The data integrity must be protected and documented (might be used as evidence in a court of law).

Initial evaluation

Scenario 7.7 could be implemented on top of a radio technology in the lower MHz band that meets the requirements regarding the bridged range of up to 15km, the coverage inside buildings and the data rate of up to 50kbit/s per link.

5.6.8 Scenario 7.8: Remote control and manipulation of Unmanned Aerial Vehicles

This scenario requires the long distance control of UAV (transmission of signals/control data to the auto pilot). The control should be possible from a person, a vehicle or the coordination center. This scenario is relevant for the categories A, B, and C starting immediately. Because the UAV is an aerial vehicle the communication scenarios A1- A3, B1 – B3 and C1 – C3 are applicable.

This scenario requires blanket radio coverage in Germany including the exclusive economic zone in the North and the Baltic Sea and also abroad (on demand). The distance between the UAV and the controller can currently not be specified. The required data rate is about 50kbit/s with up to 2 or 3 UAV in simultaneous deployment inside Germany. The communication links should be full-duplex and reliable for speeds up to 500km/h (speed of the UAV).

The service is classified as *important*. If the service relies on third party or civilian networks, it must have priority access. It must provide blanket coverage and be highly available in terms of time. Service activation and connection setup time must be very short. The data are sensitive and must be encrypted. Unauthorized interception and access by third parties (eventually even by other PPDR agencies) must be prevented. The data integrity must be protected and documented (might be used as evidence in a court of law).

Initial evaluation

Scenario 7.8 can be implemented on top of a satellite technology. There is a need to clarify how the satellite technology could be integrated into the UAV. Inside Germany, a radio network with blanket coverage that meets the requirements regarding availability and priority access could be used.

5.6.9 Scenario 7.9: Underwater voice communication

This scenario requires that multiple divers can communicate by voice with each other or a commander. The communication partners can be either in or outside the water. This scenario is relevant for all categories (A, B, and C) starting *immediately*. Hence, the applicable communications scenarios are A4, B4 and C4.

The scenario requires coverage of the operation scene. The maximum radio range between the communication partners can be up to 50 - 100m. The operation scene can be located in Germany including the exclusive economic zone in the North and the Baltic Sea and also abroad (on demand). The scenario requires a data rate of 64kbit/s with up to 10 simultaneous links at the operation scene. The communication links should be full-duplex and reliable for speeds up to 50km/h (dive commander in a boat).

The service is classified as *mission critical*. If the service relies on third party or civilian networks, it must have priority access. It must provide blanket coverage and be highly available in terms of time. Service activation and connection setup time must be very short. The data are sensitive and must be encrypted. Unauthorized interception and access by third parties (eventually even by other PPDR agencies) must be prevented. The data integrity must be protected and documented (might be used as evidence in a court of law).

Initial evaluation

Scenario 7.9 can be implemented based on a system in the MHz band that is usable for underwater communication.

5.6.10 Scenario 7.10: Networking of handheld devices or devices inside a vehicle

This scenario requires the networking of up to 8 devices (e.g head set, mobile radio, printer, laptop computer, PDA, etc.) inside a vehicle or on a person. This scenario is relevant for all categories (A, B, and C) starting *immediately*. This constitutes a new communication scenario.

It requires blanket radio coverage of an area with a diameter of about 10m. The operation scene can be located in Germany including the exclusive economic zone in the North and the Baltic Sea and also abroad (on demand). The scenario requires a data rate from the set of standardized WLAN-802.11a/g rates (e.g. 20MBit/s). The communication links should be full-duplex. The communicating devices are mobile but don't move relative to each other.

The service is classified *desirable*. It must provide blanket coverage and be highly available in terms of time. Service activation and connection setup time must be very short. The data are sensitive and must be encrypted. Unauthorized interception and access by third parties (eventually even by other PPDR agencies) must be prevented.

Initial evaluation

Scenario 7.10 can be implemented based on WLAN technologies (802.11a/g).

5.7 Interview partner 8: German Firefighters' Federation (DFV)

5.7.1 Scenario 8.1: Connecting operational and command vehicles to the control center

This scenario requires that operational and command vehicles (e.g. rescue vehicles) get connectivity to the control center. The link to the control center should provide access to the internet, too. Applications are several data communication services with the control center or through the control center with external partners (examples are transmission of images from the response area and location information to the coordination center, transmission of medical records (images, ECG, automated external defibrillator data) into the hospital, terminal access to control computers from the control vehicles and access to databases (hazardous materials databases, procedures). This scenario is relevant for categories A and C starting approximately *2013*. Hence, the applicable communications scenarios are A1, A2, C1, and C2.

It must provide blanket coverage in Germany where the maximum distance to a control center is up to 50km (category A) or up to 100km (category B). The operation scene / operation section has a diameter of up to 500m. Initially, the required data rate is 1Mbit/s, later on 2Mbit/s per link for video transmission. There can be up to 3 simultaneous links per operation scene or operation section. The communication links should be full-duplex and support mobile communication partners that move with a speed of up to 100km/h. When transmitting video, the vehicles are stationary.

The service is classified as *important*. It must provide blanket coverage and be highly available in terms of time. The connection setup time must be below 5s and the signal delay must be less than 1s. The data are sensitive (standard classification “restricted”/”VS-NfD”). A simple encryption is satisfactory.

Initial evaluation

Scenario 8.1 (with a data rate of 1Mbit/s) can be implemented based on the Public Land Mobile Network, if there is blanket coverage with HSUPA in 2013. A data rate of 2MBit/s, as required later on, is not supported by current version of HSUPA. However, further enhancements to the PLMN are planned that will support the required data rate.

5.7.2 Scenario 8.2: Data transmission from the operation scene or building to the on-site command center

This scenario requires that the operation scene or an on-site building can be connected to the on-site command center. The communication takes place between individual persons or vehicles. Personnel can be inside of buildings. Applications are the transmission of live video (e.g. from a thermal imaging camera), telemetry data, and positioning data. This scenario is relevant for categories A and C starting *immediately*. Hence, the applicable communications scenarios are A4, A5, C4, and C5.

This scenario requires blanket coverage at the operation scene or section with a maximum radius up to 250m. The required data rate is 1Mbit/s (for the thermal imaging) for up to 3 simultaneous links per operation scene or section. The communication links should be full-duplex. The communication partners are mobile and can move at walking speed.

The service is classified *important*. It must provide blanket coverage and be highly available in terms of time. The connection setup time must be below 5s and the signal delay must be less

than 1s. The data are sensitive (standard classification “restricted”/”VS-NfD”). A simple encryption is satisfactory.

Initial evaluation

The thermal imaging in scenario 8.2 can be implemented based on an ad hoc technology in the GHz band (e.g. 5.15 – 5.25GHz). Relays might be required to transmit the data from the inside of buildings. Due to the in-house communication telemetry and positioning data should be transmitted by a radio technology that uses a lower frequency band (e.g. lower MHz band).

5.7.3 Scenario 8.3: Connecting multiple control centers with radio links

This scenario requires that multiple control centers get connected to each other with radio links to provide redundancy when the primary link fails. The aim is to reduce the costs for the terrestrial link. This scenario is relevant for categories A and C starting approximately in *2012*. Connecting multiple coordination centers is a new communication scenario.

This scenario requires point-to-point links (for instance by microwave transmission) with a maximum range up to 50km (category A) or 100km (category B). In the short term the required data rate is 1Mbit/s, in the longer term 2Mbit/s. The communication links should be full-duplex, the coordination centers are stationary.

The service is classified *important*. The required availability is 98%. The availability must be statistical independent from the primary link. The links should be always on and provide a signal delay of less than 500ms. The data are sensitive (standard classification “restricted”/”VS-NfD”). A simple encryption is satisfactory.

Initial evaluation

Scenario 8.3 can be realized either per microwave transmission or alternatively per satellite. Each channel must provide a data rate of 2Mbit/s in both directions simultaneously.

5.8 Interview partner 9: German Red Cross (DRK)

5.8.1 Scenario 9.1: Data communication at the response location and with the control center

This scenario has the following requirements:

- communication at the operation scene (transmission of data from the operation scene to command posts)
- connection between the operational forces (personnel and rescue vehicles) and the control center for the operation management (staff command system and database access)
- transmission of personal data (for instance medical records)
- access to third party systems (hospitals, weather forecast etc.).

In this scenario, the personnel may be inside buildings. This scenario is relevant for all categories (A, B, and C) starting immediately. Hence, the applicable communications scenarios are A1 – A3, A5, A6, B1 – B3, B5, B6, C1 – C3, C5, and C6.

This scenario requires blanket coverage in Germany. The connection to the control center is on district level and thus the range can be many kilometers. The radius of the operation scene is in category A a few 100m, in category B and C the radius of each operation section is a few km.

Related to category A the maximum required data rate is 512kbit/s for the communication at the operation scene and 2Mbit/s (bi-directional) per link to communicate with the control center. In this category up to 8 simultaneous links per operation scene are possible. In category B and C 2Mbit/s per link are required for the communication at the operation scene. In these categories about 20 entities communicate simultaneously. Here, the required data rate per link for the communication with the control center is 4Mbit/s (bi-directional) but with only one connection per operation scene. The links shall be full-duplex and the communication partners can be mobile with a speed of 120km/h in category A and 6km/h in category B and C.

This service is classified as *mission critical*. It must provide blanket coverage and be highly available in terms of time. The call setup can be short. The data are highly sensitive (e.g. personal data) and must be encrypted.

Initial evaluation

In scenario 9.1 the communication at the operation scene can be realized by an ad hoc technology operating in the GHz-band (e.g. 5.15 – 5.25GHz). To communicate with the headquarters a new network with blanket coverage is necessary because the requirements (high bi-directional data rate up to 4Mbit/s, high availability, mission critical) can not be fulfilled by existing networks.

5.8.2 Scenario 9.2: Redundant links of the state headquarters in Germany with the federal association via a wide area network (WAN)

Due to redundancy reasons wireless WAN-links are to be realized between the state headquarters and the federal association. Additionally, also mobile stations are to be connected and communicate with each other, and even international connections are to be realized. In sum 50 locations are expected. The system will act as substitute or enhancement of the currently used system operating in the shortwave band. This scenario is only relevant for category A, starting *immediately*. As a result, the communication scenarios A1, A2, A3, and as additional scenario the redundant connection of control centers (also internationally) apply.

For this scenario point-to-point links are necessary. It has to be considered that here the range to be covered can be 600km in Germany and internationally / world-wide the range can be even longer. The required data rate per link is at least 2Mbit/s. The links shall be full-duplex and the communication partners are stationary.

This service is classified as *important*. It must provide blanket coverage and be highly available in terms of time. The call setup can be within seconds. The data must not be encrypted but protected against manipulation.

Initial evaluation

In scenario 9.2 the WAN-connection of 50 locations can be realized by satellite technology. To connect the mobile operational stations with each other also an ad hoc technology operating in the GHz band can be used as an alternative if the range is smaller than 2km or directional antennas are used.

5.9 Interview partner 10: unspecified

Because of the sensitive nature of the information provided by this interviewee, a summary cannot be included in this report. The full results are recorded in the questionnaire and were considered for the overall conclusion.

5.10 Interview partner 11: State Police Bavaria

5.10.1 Scenario 11.1: Video transmission from a helicopter to the control center / headquarters

In this scenario video from a camera installed in a helicopter is transmitted into the police headquarters by directional radio. Due to the exposed position, currently the television tower in Munich is used as receiving station. In future, also the television tower in Nuremberg will be used. From there the data is forwarded to the police headquarters. This scenario is relevant for all of the 3 categories, starting *immediately*.

In this scenario data are transmitted from the control center to the helicopter (as control channel and for the acknowledgement) and from the helicopter to the control center. Thus, the following communication scenarios A1, A2, B1, B2, C1, and C2 apply. In this context the „on-site operational forces“ of the communication scenarios are represented by the helicopter.

This scenario requires directional radio and shall be Bavarian-wide available. The maximum range to the next location with exposed position is 150km. *Own frequencies* shall be available for the police to be able to coordinate and use them under their control. Furthermore, other PPDR agencies currently also use the same frequency bands and maybe operate at the same location at the same time. The required data rate is at least 4Mbit/s and the support of high-definition video (4 – 20Mbit/s) is desired. A data rate of 500kbit/s is required for the back channel. Without considering the police special response unit in category A (normal operation) 3 and in category B and C up to 10 simultaneously links / channels are required. The link shall be full-duplex and the communication partners are mobile with a speed up to 200km/h.

Related to category C this scenario is classified as *mission critical* and related to category A and B it is classified as *important*. The service must provide blanket coverage and be highly available in terms of time. The call setup time must be short and the signal delay below 100ms. Furthermore, the data are sensitive and must be encrypted.

Initial evaluation

Scenario 11.1 can be realized by directional radio. For this own frequencies / channels are required to be able to coordinate and thus use them, namely 3 channels in category A und 10 channels in category B and C. For the video transmission a directional radio channel operating at 14GHz can be used. An additional channel is necessary for the back channel that provides 500kbits.

5.10.2 Scenario 11.2: Video transmission using DVB-T

In this scenario a video picture of a fixed installed or a mobile camera (carried by a person or installed in a vehicle) is transmitted into the headquarters using DVB-T (2.3GHz). Due to the already trained staff DVB-T shall continue to be used but the currently available 5 channels are

not sufficient. This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. Here, data are exchanged between control center / headquarters and operation scene and persons can even be inside buildings. As result, the following communication scenarios A1, A2, A5, B1, B2, B5, C1, C2, and C5 apply.

This scenario requires Bavarian-wide blanket coverage for DVB-T. The range to the next location with an exposed position is 30km at the maximum. *Own frequencies* shall be available for the police to be able to coordinate and use them under their control. The required data rate is at least 4Mbit/s and the support of high-definition video (4 – 20Mbit/s) is desired. A data rate of 500kbit/s is sufficient for the back channel. Without considering the police special response unit in category A 3 and in category B and C up to 15 simultaneously links / channels are required. The link shall be full-duplex and the communication partners are mobile with a speed up to 200km/h.

Related to category B and C this scenario is classified as *mission critical* and related to category A it is classified as *important*. The service must provide blanket coverage and be highly available in terms of time. The call setup time must be short and the signal delay shall be below 100ms. Furthermore, the data are sensitive and must be encrypted.

Initial evaluation

Scenario 11.2 requires a network with blanket coverage using DVB-T at 2.3GHz. For this own frequencies / channels are required, namely 3 channels in category A and 15 channels in category B and C. Additionally, each channel must come with an own back channel providing a data rate of 500kbit/s.

5.10.3 Scenario 11.3: Connection of vehicles / persons / locations to the police headquarters

In this scenario vehicles, persons, or temporary locations are connected to the police headquarters by network links to exchange video (not high-definition) and data (e-mail, data bases, intranet, etc.). This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. Here, data are exchanged between the control center / headquarters and the operation scene (person, vehicle, or location), whereas persons can also be within buildings. Thus, the following communication scenarios A1, A2, A5, B1, B2, B5, C1, C2, and C5 apply.

This scenario requires Bavarian-wide blanket coverage. *Own frequencies* shall be available for the police to be able to coordinate and use them under their control. The required bidirectional data rate is 4Mbit/s (2Mbit/s for video and 2Mbit/s for data). In category A 5-10 and in category B and C up to 20 simultaneously links will be resulting per operation scene. The link shall be full-duplex and the communication partners are mobile with a speed up to 200km/h (category A and B) and up to 100km/h (category C).

This scenario is classified as *important*. If other communication possibilities are failing the service can also be *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time for emergency calls must be short; otherwise the setup can be within seconds. The signal delay shall be below 500ms. Furthermore, the data are sensitive and must be encrypted.

Initial evaluation

Scenario 11.3 requires an own new network with blanket coverage because the requirements (high data rates of 20x4Mbit/s, mission critical, high availability) cannot be fulfilled by existing networks. A challenging aspect of the realization is the requirement of an in-house coverage.

5.10.4 Scenario 11.4: On-site communication available for different applications

In this scenario vehicles communicate with vehicles or persons at the operation scene. This scenario is relevant for all of the 3 categories A, B, and C, starting *in the medium term*. As a result, the communication scenarios A3, B3, and C3 apply.

Blanket coverage of the operation scene is required with a maximum range of 2km between the communication partners. The required bandwidth is 2.5Mbit/s between the vehicles (2Mbit/s for video and 500kbit/s for data). Up to 5 vehicles can be located at the operation scene. The links shall be full-duplex and the communication partners are mobile with a speed up to 200km/h.

This scenario is classified as *desirable*. The service must provide blanket coverage and be highly available in terms of time. The call setup time shall be within seconds and the signal delay below 500ms. Furthermore, the data are sensitive and must be encrypted.

Initial evaluation

Scenario 11.4 can be realized by an ad hoc technology operating in the GHz band (e.g. 5.15 – 5.25GHz).

5.10.5 Scenario 11.5: Connectivity of relay stations with the headquarters

In this scenario relay stations are connected with the police headquarters (e.g. by directional radio, 14 GHz). This case represents a new communication scenario that is relevant for all of the 3 categories A, B, and C, starting *immediately*.

The scenario requires directional radio with a maximum range of 150km. *Own frequencies* shall be available for the police to be able to coordinate and use them under their control. Related to scenario A the required bandwidth is at least 20Mbit/s (between the Olympic tower and the police headquarters) and related to category B and C 28Mbit/s (between the Olympic tower and the police headquarters). If transmitting high-definition video pictures the requirement would be approximately 4 times as much bandwidth. A bandwidth of 500kbit/s is sufficient for the back channel. In category A up to 5 and in category B and C up to 10 simultaneously links are required. The links shall be full-duplex and the communication stations are stationary.

This scenario is classified as *mission critical* related to the category B and C and classified as *important* in category A. The service must provide blanket coverage and be highly available in terms of time. The call setup time must be short and the signal delay shall be below 100ms. Furthermore, the data are sensitive and must be encrypted.

Initial evaluation

Scenario 11.5 requires directional radio with one channel per link. Thus, 10 channels are resulting (maximum requirement in category B and C). Alternatively, this scenario could also be realized by satellite links. Additionally, each video channel has to come with a back channel of 500kbit/s.

5.11 Interview partner 12: State Police Brandenburg

5.11.1 Scenario 12.1: Mobile data connection of police patrol cars with the headquarters

In this scenario police patrol cars are connected mobile to the headquarters. Mentioned applications are for instance mobile computing (form filling, access to data bases (POLAS)), video transmission, and the data exchange with the control center. Except the video transmission the applications shall be available to policemen who are located in an area up to 50m around the vehicle (also inside buildings or cellars). This scenario is relevant for all of the 3 scenarios A, B, and C, starting *immediately*. Here, data are exchanged between the operation scene and the control center and persons can also be in buildings. As a result, the following communication scenarios A1, A2, A5, B1, B2, B5, C1, C2, and C5 apply.

This scenario requires blanket coverage within Brandenburg with a maximum range of 250km to the headquarters. As bandwidth 3Mbit/s are required (2Mbit/s for video and 1Mbit/s for data). In the whole state Brandenburg at the maximum 15-30 simultaneously video and 225 simultaneous data connections are to be established. The number of connections per operation scene cannot be specified. The links shall be full-duplex and the communication partners are mobile with a speed up to 200km/h.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The quality must be high, the call setup time and the signal delay short. Furthermore, the data are sensitive and must be encrypted.

Initial evaluation

Scenario 12.1 requires an own new network with blanket coverage because the requirements (high data rate of 2-3Mbit/s in the uplink, mission critical, guaranteed bandwidth, high availability) cannot be fulfilled by existing networks. A challenging aspect of the realization is the requirement of an in-house coverage.

5.11.2 Scenario 12.2: Data synchronization near a control center

In this scenario police patrol cars perform data synchronization when they are nearby a control center. The patrol cars are here stationary and located in the outside or even inside a parking garage. This scenario is relevant for all of the 3 scenarios A, B, and C, starting *immediately*. As a result, the communication scenarios A1, A2, B1, B2, C1, and C2 apply.

This scenario requires blanket coverage at the control centers within an area of a diameter less than 1km. As bandwidth 5Mbit/s per patrol car and in sum 50Mbit/s (full-duplex) at the control center are required.

This scenario is classified as *important*. The service must be highly available in terms of time and the synchronization shall start shortly after the arrival of the car. Furthermore, the data are sensitive and must be encrypted.

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Initial evaluation

Scenario 12.2 can be realized by an ad hoc technology operating in the GHz band (e.g. 5.15 – 5.25GHz). If necessary, the data rate of 50Mbit/s has to be realized by the usage of more than one channel.

5.11.3 Scenario 12.3: Video and data transmission between vehicles

In this scenario videos and pictures (e.g. photographs) are transmitted from vehicle to vehicle. This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. As a result, the communication scenarios A3, B3, and C3 apply.

This scenario requires blanket coverage at the operation scene within a range up to about 15km between the operation scene and approaching vehicles and up to 5km between vehicles at the operation scene. As bandwidth 2Mbit/s (full-duplex) between two vehicles are required. The number of simultaneous links strictly depends on the scenario and cannot be specified more detailed. The communication partners are mobile with a speed up to 200km/h.

This scenario is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time must be short and the signal delay shall be within a few seconds.

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Initial evaluation

Due to the connection of approaching vehicles an own new network with blanket coverage is necessary because the requirements (high data rate of 2Mbit/s, mission critical, guaranteed bandwidth, and high availability) cannot be fulfilled by existing network. The on-site communication can be realized by an ad hoc technology operating in the GHz band (e.g. 5.15 – 5.25GHz).

5.12 Interview partner 13: State Police North Rhine-Westphalia

5.12.1 Scenario 13.1: Video transmission from a helicopter / airplane to a central interconnection point into the police network

In this scenario a video picture is transmitted from a camera installed in a helicopter / airplane to a central interconnection point (handover) into the police network and from there forwarded via landline. Currently, two of such interconnection points exist and for the transmission to these points directional radio is used. Here, the flying object can be in an altitude up to 460m. This scenario is relevant for all of the 3 scenarios A, B, and C, starting *immediately*. If defining in this scenario the helicopter / airplane as operation scene and the interconnection point into the police network as headquarters then as a result the communication scenarios A1, A2, B1, B2, C1, and C2 apply.

This scenario requires directional radio to cover at least a range of 150km (desirable 220km). The required data rate for video (uplink) is at least 4Mbit/s. In future, also the usage of a high-definition camera (4 – 20Mbit/s) shall be possible. To control the camera only a few kbit/s are necessary. 10 flying objects are used simultaneously at the maximum. The link shall be full-duplex (for control data) and the flying objects move with a speed up to 150km/h.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time must be within a few seconds at the maximum and the signal delay must be below 1s. Furthermore, the data are sensitive and must be encrypted. Due to security reasons an own network is required.

Initial evaluation

In scenario 13.1 the video transmission can be realized by directional radio, e.g. operating at 14GHz. additionally, a back channel providing a bandwidth of a few kbit/s shall be available.

5.12.2 Scenario 13.2: Video transmission from a UAV to a ground vehicle

In this scenario a video picture is transmitted from a camera installed at a UAV to a ground vehicle. This scenario is relevant for all of the 3 scenarios A, B, and C, starting *immediately*. As a result, the communication scenarios A3, B3, and C3 apply.

This scenario requires blanket coverage between UAV and ground vehicle up to a range between the communication partners of 5 -10km (desirable 20km). The required data rate for video (uplink) is at least 4Mbit/s. In future, also the usage of a high-definition camera (4 – 20Mbit/s) shall be possible. To control the camera only a few kbit/s are necessary. Only one UAV is used. The link shall be full-duplex (for control data) and the UAV move with a speed up to 50km/h.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time must not exceed a few seconds and the signal delay must be below 1s. Furthermore, the data are sensitive and must be encrypted. Due to security reasons an own network is required.

Initial evaluation

Scenario 13.2 requires an own new network with blanket coverage because the requirements (high data rate per connection of at least 4Mbit/s in the uplink, mission critical, high availability) cannot be fulfilled by existing networks and furthermore an own network is required.

5.12.3 Scenario 13.3: Video transmission from permanently fixed installed cameras to a central interconnection point into the police network

In this scenario video pictures from permanently fixed installed cameras are transmitted to a central interconnection point (handover) into the police network and from there forwarded via landline e.g. into the headquarters. Currently, two of such interconnection points exist. Also the control of the camera shall be possible. This scenario is relevant for all of the 3 scenarios A, B, and C, starting *immediately*. The cameras can also be installed inside buildings. As a result, the communication scenarios A1, A2, A5, B1, B2, B5, C1, C2, and C5 apply.

This scenario requires blanket coverage within North Rhine-Westphalia. The required data rate for video (uplink) is at least 4Mbit/s. In future, also the usage of a high-definition camera (4 – 20Mbit/s) shall be possible. To control the camera only a few kbit/s are necessary. The number of cameras operating simultaneously cannot be specified. The links shall be full-duplex (for control data) and the cameras are stationary.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup must be within a few seconds at the maximum and the signal delay must be below 1s. Furthermore, the data are sensitive and must be encrypted. Due to security reasons an own network is required.

Initial evaluation

Scenario 13.3 requires an own new network with blanket coverage because the requirements (high data rate per connection of at least 4Mbit/s in the uplink, mission critical, high availability)

cannot be fulfilled by existing networks and furthermore an own network is required. A challenging aspect of the realization is the requirement of an in-house coverage.

5.12.4 Scenario 13.4: Transmission of sensor data to a central interconnection point into the police network

In this scenario sensor data are transmitted to a central interconnection point into the police network and from there forwarded via landline e.g. into the headquarters. Currently, two of such interconnection points exist. One example for relevant sensors are contact sensors installed on doors or windows for the purpose of object protection. This scenario is relevant for all of the 3 scenarios A, B, and C, starting *immediately*. The sensors can also be installed inside buildings. As a result, the communication scenarios A1, A2, A5, B1, B2, B5, C1, C2, and C5 apply.

This scenario requires blanket coverage within North Rhine-Westphalia. The required data rate per sensor is only a few kbit/s but the number of sensors per operational area can be very high. The exact specification of the number is not possible. The links shall be full-duplex and the sensors can even move with a speed up to 200km/h (e.g. if installed in a vehicle).

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time and the signal delay must be below 1s. Furthermore, the data are sensitive and must be encrypted. Due to security reasons an own network is required.

Initial evaluation

Scenario 13.4 requires also an own new network with blanket coverage because the requirements (mission critical, high availability) cannot be fulfilled by existing networks and furthermore an own network is required. For this application the required bandwidth cannot be specified.

5.12.5 Scenario 13.5: Connectivity of motorized police patrols (car and motorcycle)

In this scenario motorized patrols (car and motorcycle) are connected to the police network (via a central interconnection point into the police network). The patrols are equipped with cameras. Pictures of these cameras are transmitted into the police network. Furthermore, video data from fixed installed cameras (e.g. inside a bank building) are transmitted to the patrols via the police network. Additionally, a variety of further applications is planned, e.g. access to data bases or the transmission of status data from the vehicle. This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. Patrols can also be inside tunnels or parking garages. As a result, the communication scenarios A1, A2, A5, B1, B2, B5, C1, C2, and C5 apply.

This scenario requires blanket coverage within North Rhine-Westphalia. The required data rate for vehicles with the task of the preservation of evidence is at least 4Mbit/s. In future, also the data rates of high-definition cameras (4 – 20Mbit/s) shall be supported. For regular patrols a data rate up to 4MBit/s (for two cameras) results. At the maximum 10 patrols can be at the operation scene. The links shall be full-duplex and the patrols are mobile with a speed up to 250km/h.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time and the signal delay must be below 1s.

Furthermore, the data are sensitive and must be encrypted. Due to security reasons an own network is required.

Initial evaluation

Scenario 13.5 requires an own new network with blanket coverage because the requirements (high data rate per connection of at least 4Mbit/s in the uplink, mission critical, high availability) cannot be fulfilled by existing networks and furthermore an own network is required. A challenging aspect of the realization is the requirement of an in-house coverage.

5.12.6 Scenario 13.6: Mobile command centers by land and by sea

In this scenario mobile command centers are used and connected to the police network. In addition to the applications and services of scenario 5 (see chapter 5.12.5) further applications apply like the connection of UAVs and mobile and fixed installed cameras with the on-site mobile command center, or the data forwarding to the headquarters. This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. Cameras can also be installed inside buildings. As a result, the communication scenarios A1, A2, A3, A5, B1, B2, B3, B5, C1, C2, C3, and C5 apply.

This scenario requires blanket coverage within North Rhine-Westphalia. The data rate between the communication partners shall be at least 4Mbit/s. In future, also the data rates of high-definition cameras (4 – 20Mbit/s) shall be supported. Related to category A there is only one and related to category B and C there are up to 60 operational spots (cameras, UAVs, or mobile command centers) at the operation scene. The links shall be full-duplex and the mobile operational spots are mobile with a speed up to 250km/h.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time and the signal delay must be below 1s. Furthermore, the data are sensitive and must be encrypted. Due to security reasons an own network is required.

Initial evaluation

Scenario 13.6 requires an own new network with blanket coverage because the requirements (high data rate per connection of at least 4Mbit/s in the uplink, mission critical, high availability) cannot be fulfilled by existing networks and furthermore an own network is required. A challenging aspect of the realization is the requirement of an in-house coverage.

In scenario 13.6 the communication between mobile or fixed installed cameras and the mobile command center could also be realized in some cases by an ad hoc technology operating in the GHz band. But the realizability depends on the range and the attenuation of the signals by buildings.

5.12.7 Scenario 13.7: Connectivity of non-motorized police patrols (cyclist, horseman, pedestrian)

In this scenario non-motorized patrolmen are connected to the police network (via a central interconnection point into the police network). The policemen use handhelds for the purpose of data gathering, access to data bases, or transmission of a photo or finger print. This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. Policemen can also be

inside buildings. As a result, the communication scenarios A1, A2, A5, B1, B2, B5, C1, C2, and C5 apply.

This scenario requires blanket coverage within North Rhine-Westphalia. The required data rate is at least 512kbit/s (desired 1Mbit/s). There are at the maximum 10 policemen at the operation scene. The links shall be full-duplex and the policemen are stationary during the data transmission.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time shall be within a few seconds and the signal delay below 1s. Furthermore, the data are sensitive and must be encrypted. Due to security reasons an own network is required.

Initial evaluation

Also scenario 13.7 requires an own new network with blanket coverage because the requirements (mission critical, high availability) cannot be fulfilled by existing networks and furthermore an own network is required. The required data rate for this scenario is 512kbit/s.

5.12.8 Scenario 13.8: Communication with a robot to defuse explosive devices

In this scenario data are transmitted between a mobile robot and operational spots at the operation scene for the purpose of defusing explosive devices, also inside buildings. This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. As a result, the communication scenarios A3, A5, B3, B5, C3, and C5 apply.

This scenario requires blanket coverage between the robot and the operational spot with a maximum range of 100m. The video transmission from the robot to the operational spot requires at least 4Mbit/s. In future, also the data rates of high-definition cameras (4 – 20Mbit/s) shall be supported. In this scenario only one robot is at the operation scene. The link shall be full-duplex and the robot moves at the maximum with walking speed.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time shall be within a few seconds and the signal delay below 1s. Furthermore, the data are sensitive and must be encrypted. Due to security reasons an own network is required.

Initial evaluation

Scenario 13.8 can be realized with an ad hoc technology operating in the GHz band (e.g. 5.15 – 5.25GHz).

5.13 Interview partner 16: Fire Protection and Disaster Control, Rural District Potsdam Mittelmark

One of the applications is the voice communication. However, there is a good or even very good availability provided by existing systems (TETRA, analogues radio in the 2m / 4m band) that is sufficient to normal operation and mass events. Up to now, experiences concerning a major disaster are not gained. This operation category is likely to be feasible by using mobile base stations.

5.13.1 Scenario 16.1: Video transmission to the operation leader

In this scenario video pictures are transmitted from a camera to the on-site operation leader. The camera can be carried by a person, be located in a helicopter, or be fixed installed, e.g. at a pole. The type of the camera can also be a thermal imaging camera and it can also be operated inside buildings. This scenario is relevant for all of the 3 scenarios A, B, and C, starting *immediately*. As a result, the communication scenarios A3 - A5, B3 – B5, and C3 – C5 apply.

This scenario requires blanket coverage at the operation scene. Related to category A the maximum radius of the operation scene is 300m, related to category B and C the maximum radius is 5km. The required data rate is 4Mbit/s for 1 high-definition camera in category A. In category B 2 high-definition cameras (each 4Mbit/s) and 3 – 4 cameras with low resolution are required at the maximum. Thus, in sum the required bandwidth is about 10Mbit/s. In category C 2 high-definition cameras with an overall bandwidth of 8Mbit/s are required. The links shall be full-duplex and the communication partners are mobile with a speed up to 20km/h.

This service is classified as *mission critical*. The service must provide blanket coverage but the infrastructure can also be deployed ad hoc. The activation time of the service must not exceed 1min and the signal delay can be a few seconds. The data are sensitive (especially if person-related data) and must be secured against interception and manipulation.

Initial evaluation

In scenario 16.1 the transmission of the high-definition videos can either be realized using DVB-T (operating at 2.3 GHz) or alternatively using an ad hoc technology operating in the GHz band (e.g. 5.15 – 5.25GHz). Pictures from cameras with low resolution or a thermal imaging camera are usually transmitted via a data network than can be realized with an ad hoc technology operating in the GHz band (e.g. 5.15 – 5.25GHz).

5.13.2 Scenario 16.2: Data applications

This scenario represents data applications like the access to a data base in the control center or internet (ministries, registration office, weather service, experts, etc.) and the transmission of data to the control center (e.g. data of injured people). This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. As a result, the communication scenarios A1, A2, A6, B1, B2, B6, C1, C2 and C6 apply.

This scenario requires blanket coverage with a range of up to 150km between the control center and the operation scene. The required data rate is at the maximum 2Mbit/s per operation scene. The links shall be full-duplex and the communication partners are located stationary.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time must be within a few seconds. The data are sensitive and must be encrypted. Only authorized people may have access.

Initial evaluation

Scenario 16.2 requires the deployment of a new network with blanket coverage because the requirements (mission critical and high availability) cannot be fulfilled by existing networks.

5.13.3 Scenario 16.3: Monitoring of respiratory protection devices

This scenario considers the monitoring of respiratory protection devices at the operation scene with the requirement of an interoperability of different systems that are available on the market. The respiratory protection devices are carried by persons who also can be inside buildings. Due to the relevance of this scenario for the categories A and C, starting *immediately*, the communication scenarios A4, A5, C4, and C5 apply.

This scenario requires blanket coverage at the operation scene. Here, the operation scene and accordingly an operation section represents an area with a maximum radius of 300m. The required maximum data rate is 2Mbit/s per operation scene or operation section. The links shall be full-duplex and the communication partners are mobile with a speed up to 20km/h.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time and the signal delay must be short. The data are sensitive, must be encrypted, and secured against manipulation.

Initial evaluation

Due to the usage also inside buildings scenario 16.3 the monitoring of respiratory protection devices in scenario 16.3 should be operated in a frequency range below 1 GHz (e.g. in the lower MHz-band).

5.14 Interview partner 17: Federal Agency for Technical Relief (THW)

5.14.1 Scenario 17.1: Connectivity of operational spots und connectivity to the internet

In this scenario on-site operational spots are connected together and accordingly to the control center or even the internet, whereas accessing the internet the communication path leads via the control center. Currently, directional radio is used. But also the usage of satellite technology would be possible. This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. As a result, the applications A1 – A3, B1 – B3, and C1 – C3 apply.

This scenario requires point-to-point links with a maximum range of 40km. Related to category A the required data rate is 4Mbit/s and related to the categories B and C the required data rate is 8Mbit/s. For all categories only one channel is required that is used by several directional radio links, if necessary. The links shall be full-duplex and the communication partners are located stationary.

Due to the dependence of the operation a classification of this service (mission critical, important, or desirable) cannot be specified. The service must be highly available in terms of time. The positioning of the antennas can be selected flexibly to ensure a high link quality (e.g. line of sight). The call setup time must be short and the signal delay below 500ms. The data sensitivity depends on the operation. An own system is desired for operating the directional radio link.

Initial evaluation

Scenario 17.1 can be realized by directional radio (alternatively also by satellite) with the requirement of a channel that supports up to 8Mbit/s full-duplex.

5.14.2 Scenario 17.2: Connectivity at the operation scene

In this scenario the operation scene connectivity at the operation scene is provided to realize applications like telemetry (respiratory protection, positioning information), monitoring of generators and vehicles, networking of sensors (e.g. detection of motion of buildings that are in danger of collapsing), and the communication with UAVs for the purpose of video transmission. Also the direct access to the internet (e.g. by PDA) shall be made possible. Here, persons can also be inside buildings. This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. As a result, the applications A3 – A6, B3 – B6, and C3 – C6 apply.

This scenario requires blanket coverage of the operational area. Related to category A the radius of the operational area is 5km, related to category B 100km, and related to category C a German-wide coverage is required. The required data rate is 4Mbit/s in category A and 8Mbit/s for the categories B and C once per area. The links shall be full-duplex and the communication partners can be mobile (UAVs with a speed up to 120km/h, vehicles up to 100km/h).

Concerning the telemetry application this service is classified as *mission critical*, apart from the telemetry it is classified as *important*. The service must provide blanket coverage and be highly available in terms of time. The call setup time must be short and the signal delay below 500ms. The data sensitivity depends on the operation. Only for the transmission of telemetry data an own system is desired.

Initial evaluation

In scenario 17.2 the categories have to be considered differently:

- In category A the connection of the UAV can be realized by an ad hoc technology in the GHz band (e.g. 5.15 – 5.25GHz). Concerning sensors and telemetry, that have to operate inside buildings, an on-site communication system with a frequency below 1 GHz should be used (e.g. in the lower MHz band). To connect clusters over longer ranges in the outside also an ad hoc technology in the GHz band (e.g. 5.15 – 5.25GHz) can be used.
- Due to the dimension of the operational area (100km and accordingly German-wide) and the requirements (mission critical concerning telemetry, high availability, high data rate of 8Mbit/s, own network for telemetry) an own network with blanket coverage is necessary. If coverage inside buildings is not given an additional technology operating at a frequency below 1 GHz (e.g. in the lower MHz band) has to be used on-site for the operation of sensors and telemetry inside buildings.

5.14.3 Scenario 17.3: Connection of the abroad operational scene to the headquarters in Germany

In this scenario the abroad operational scene is connected to the headquarters in Germany or the internet. As application voice and video transmission are mentioned. Currently, this scenario is realized by satellite (Iridium, Inmarsat), whereas the THW desires an own satellite capacity. This scenario is relevant for the categories A and C, starting *immediately*. As a result, the communication scenarios A1, A2, A6, B1, B2, B6, C1, C2, and C6 apply.

This scenario requires worldwide blanket coverage. The required data rate is 500kbit/s available for the operation leadership. There is only one operation leadership per operation scene. The links should be full-duplex and the operational leadership are mobile with a speed up to 100km/h

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup time must be short and the signal delay below

500ms if possible. The data sensitivity depends on the operation. There is no requirement of an own network or technology.

Initial evaluation

Scenario 17.3 can be realized by satellite technology, e.g. by Inmarsat BGAN.

5.15 Interview partner 18: Fire Brigade of the Technical University (TU) of Munich

5.15.1 Scenario 18.1: Data exchange with the control center

In scenario 18.1 data are exchanged between the on-site operational forces and the control center. Here, operational forces need access to primary information (information directly related to the operation) and secondary information (information supporting the operation). Furthermore, the operation documentation is maintained, whereas concerning health care also external doctors to check the patient´s condition are involved (remote doctor). Additionally, in this scenario also administrative tasks are done like maintenance or preventive fire protection. This scenario is relevant for all of the 3 categories A, B, and C, starting immediately. As a result, the communication scenarios A1, A2, A6, B1, B2, B6, C1, C2, and C6 apply.

This scenario requires blanket coverage around the area of the TU Munich in Garching. Besides the location of the TU in Garching also the TU location in Weihenstephan is to be connected to the network. Thus, the stated maximum range of the operational area of 40km is resulting. The communication between these two locations can be realized by directional radio, satellite link, or landline. The required data rate is in total of 22Mbit/s per operation scene and accordingly operation section. 4Mbit/s of the total data rate is needed for the transmission of the primary information; the remaining data rate is needed for documentation and administrative tasks. The links shall be full-duplex and the communication partners are mobile with a speed up to 120km/h.

Access to primary information is classified as *mission critical*, access to secondary information and documentation as *important*, and administrative tasks as *desirable*. The service must provide blanket coverage and be highly available in terms of time. The call setup must be immediately. The data are sensitive and must be encrypted (e.g. by IPsec).

Initial evaluation

Scenario 18.1 can be realized with an ad hoc technology operating in the GHz-band (e.g. 5.15 – 5.25GHz), whereas parts of the network should be pre-installed at strategic locations on the site of the TU Munich (e.g. high buildings) to achieve a partial blanket coverage (e.g. 60 – 70%). During operation, the pre-installation can be complemented by mobile network components. To connect the sites in Garching and Weihenstephan directional radio, satellite communication, or a landline can be used.

5.15.2 Scenario 18.2: Data transmission at the operation scene

In scenario 18.2 data are transmitted at the operation scene using applications like monitoring of respiratory protection devices, transmission of information concerning hazardous materials (NBC, etc.), BodyNets (sensors), triage systems (process of determining the priority of patients' treatments based on the severity of their condition using RFID), gathering of vehicle status, usage of a thermal imaging camera, usage of a command and control system, and a 3D object

location of individuals in objects (without any pre-installation). In this scenario, vehicles, operational spots, and individual persons communicate with each other, whereas the persons also can be inside buildings. This scenario is relevant for all of the 3 categories A, B, and C, starting *immediately*. As a result, the applications A3 – A5, B3 – B5, and C3 – C5 apply.

This scenario requires blanket coverage of the operation scene. Related to category A the radius of the operational scene is 600m, related to category B 1.2km, and related to category C also more than 1.2km. The required data rate available for the fire brigade of the TU Munich is 15Mbit/s per operation scene or per operation section. But it has to be considered that according to the fire brigade during an operation of category B and C up to 5 PPDR agencies will be involved. The links shall be full-duplex and the communication partners are mobile with a speed up to 120km/h.

Gathering of a vehicle status and usage of a thermal imaging camera are classified as *important*. The other applications are classified as *mission critical*. The service must provide blanket coverage und must be highly available in terms of time. The call setup must be immediately. The data are sensitive and must be encrypted (e.g. by IPsec).

Initial evaluation

In scenario 18.2 the on-site data network can also be realized with an ad hoc technology in the GHz band. The users could be connected to the network by WLAN technology. Concerning the in-house coverage (e.g. necessary for the monitoring of the respiratory protection devices) a system operating at a frequency lower than 1 GHz (e.g. in the lower MHz band) would be advantageous.

5.15.3 Scenario 18.3: Connection of fire detection systems to the control center

Due to redundancy and flexibility reasons in scenario 18.3 fire detection systems of buildings should be connected with the control center by radio. Additionally, the fire detection systems inside the building should be connected by radio. This scenario is only relevant for category A, starting *immediately*. As a result the communication scenarios A1, A2 and A5 apply as well as a new communication scenario, namely the connectivity of fire detection systems inside a building.

This scenario requires blanket coverage inside the buildings as well as point-to-point links between the buildings and the control center that cover ranges up to 40km. The required data rate is 4Mbit/s inside the building and 4Mbit/s for the communication link with the control center. The links shall be full-duplex and the communication partners are located stationary.

This service is classified as *mission critical*. It must provide blanket coverage. The call setup time must be very short and the signal delay short. The data are sensitive and must be encrypted (e.g. by IPsec).

Initial evaluation

In scenario 18.3 a WLAN technology can be used to establish the communication network for the fire detection systems inside a building. The connection of the fire detection systems to the control center can either be realized by directional radio or satellite communication. There, each channel must operate in full-duplex mode and provide a bidirectional data rate of 4Mbit/s.

5.15.4 Scenario 18.4: Communication at the operation scene and with the control center

This scenario represents the communication at the operation scene and with the control center. A possible application is VoIP as substitute / complement to the currently used radio technology especially for the in-house coverage. Furthermore, relevant aspects are the alerting (e.g. per pager) and the individual monitoring (dead man´s switch). In this scenario, the operational forces communicate with the control center and vehicles and individuals communication at the operation scene. This scenario is relevant for all of the 3 categories A, B und C, starting *immediately*. As a result, the communication scenarios A1 - A5, B1 – B5, und C1 – C5 apply.

This scenario requires blanket coverage of the operation scene. Related to category A the radius of the operation scene is 600m, related to category B 1.2km, and related to category C also more than 1.2km. In addition, also the link between the operation scene and the control center requires blanket coverage with a range of 40km because not only the location in Garching but also the location Weihenstephan has to be considered. The required data rate available for the fire brigade of the TU Munich is 11Mbit/s (realized as one channel / shared medium) per operation scene and accordingly per operation section. But it has to be considered that according to the fire brigade during an operation of category B and C up to 5 further PPDR agencies will be involved. The links shall be full-duplex and the communication partners are mobile with a speed up to 200km/h.

This service is classified as *mission critical*. The service must provide blanket coverage and be highly available in terms of time. The call setup must be immediately. The data are sensitive and must be encrypted (e.g. by IPsec).

Initial evaluation

In scenario 18.4 the communication network at the operation scene can be realized with a WLAN technology in combination with an ad hoc technology operating in the GHz-band. The WLAN technology can be used for the wireless connection of users to the network. The ad hoc technology can be used for the communication of the network nodes among themselves. The connection of the sites in Garching and Weihenstephan can be realized by directional radio, satellite communication, or a landline. The link has to fulfil the requirement of a channel that operates in full-duplex mode and provides a bidirectional data rate of 11Mbit/s.

5.16 Interview partner 19: BASF Fire Brigade

5.16.1 Scenario 19.1: Data transmission between control center and on-site operation leadership

Scenario 5.16.1 represents the data exchange between the control center of the BASF fire brigade (located at the industrial site) and the operation leadership at the operation scene. Videos, site maps, information (text files), or measured data (gas detectors, weather data) are transmitted, communication links between the command center of the fire brigade and on-site mobile command vehicles are established, and also a communication link between the site management and the operation leadership is established. Generally, only the categories A und C are relevant for the BASF fire brigade. As a result the communication scenarios A1, A2, A6, C1, C2 and C6 apply, starting *immediately*.

This scenario requires blanket coverage of the operational area. Related to category A the factory site represents the operational area (radius approx. 2km), whereas for category C the

operational area is extended over the factory site (radius approx. 3km). The required data rate is 2Mbit/s per vehicle. In category A only 1 vehicle is used, whereas in category C up to 3 vehicles are needed. The links shall be full-duplex and the communication partners are stationary.

This service is classified as *important*. The service must provide blanket coverage and be highly available. The call setup must be short. The data are highly sensitive and must be encrypted.

Initial evaluation

Scenario 5.16.1 can be realized with an ad hoc technology using the GHz-band (e.g. 5.15 – 5.25GHz), whereas for the blanket coverage of the factory site network nodes / relays should be pre-installed at strategic locations (e.g. high buildings). Alternatively, this scenario can also be realized using the public land mobile network, whereas an uplink of 2Mbit/s is currently not provided.

5.16.2 Scenario 19.2: Connectivity at the operation scene: Data transmission from operation scene to mobile command vehicle

In this scenario data are transmitted from the operation scene to the mobile command vehicle. The data consist e.g. of video data of the operation scene (also pictures from a robot equipped with a camera or an UAV), measured data (gas detectors, weather data), vital signs of the human body (pulse, temperature, etc.), and respiratory protection data. The communication partners are vehicles, mobile operation centers and persons, whereas the persons can also be inside buildings. Generally, only the categories A und C are relevant for the BASF fire brigade. As a result the communication scenarios A3 – A5 and C3 – C5 apply, starting *immediately*.

This scenario requires blanket coverage of the operational area. Related to category A the radius of operational area is 500m at the maximum, whereas for category C the radius of the operational area is 600m at the maximum. The UAV can fly in an altitude up to 200m. Concerning category A, the required data rate is 2Mbit/s at the operation scene. In category C also 2Mbit/s are required but the operation could consist of up to 4 single operation sections. The links shall be full-duplex and the communication partners are mobile with a speed up to 10kmh.

This service of monitoring of the respiratory protection devices is classified as *mission critical*, besides this special application as *important*. The service must provide blanket coverage and be highly available in terms of time. The call setup time and the signal delay must be short. The data are highly sensitive and must be encrypted.

Initial evaluation

Scenario 19.2 could be realized with an ad hoc technology in the GHz-band (e.g. 5.15 – 5.25GHz), whereas concerning the in-house coverage for the telemetry application a technology should be used operating in a lower frequency band (e.g. the lower MHz band).

5.16.3 Scenario 19.3: Data transmission from measuring station to mobile command vehicle

In this scenario data (e.g. of a process control system) are transmitted from the measuring station to the mobile command vehicle. Generally, only the categories A und C are relevant for

the BASF fire brigade. As a result the communication scenarios A3 and C3 apply, starting *immediately*.

The realization of this scenario requires blanket coverage of the operation scene (radius 500m at the maximum). The required data rate is 1Mbit/s at the operation scene. The links can be semi-duplex and the communication partners are stationary when using the service.

This service is classified as *important*. The service must provide blanket coverage and be highly available in terms of time. The call setup time and the signal delay must be short. The data are highly sensitive and must be encrypted.

Initial evaluation

Scenario 19.3 can be realized with an ad hoc technology in the GHz-band (e.g. 5.15 – 5.25GHz).

5.17 Interview partner 20: German Customs Administration

5.17.1 Scenario 20.1: Data communication and data queries

In this scenario laptops installed in vehicles should be connected with the headquarters for the purpose of data communication and data queries. This scenario is only relevant for category A, starting *immediately*. As a result the communication scenarios A1 and A2 apply.

This scenario requires a German-wide coverage to connect the vehicles to 5 control centers. A maximum data rate of 4Mbit/s is needed (only one vehicle per operation area). The main data traffic will be generated in the downlink. The connection links shall be full-duplex. The vehicles are positioned stationary during the usage of the service.

This service is classified as *important*. The service has to be available at locations where control stations are reasonable (highways, cities, etc.) and at locations that show a typical coverage of the cellular radio network. In terms of time delays are acceptable, and a typical availability of the cellular radio network is sufficient. A call setup should be a matter of seconds, and the signal delay is stated as not very critical. The data are sensitive and must be encrypted. Public networks can be used.

Initial evaluation

Scenario 20.1 can be realized with the public land mobile network if HSDPA is available with the required coverage.

5.17.2 Scenario 20.2: Transmission of video and picture data

In this scenario videos and pictures are to be transmitted between 2 on-site vehicles and between vehicle and the headquarters. This scenario is only relevant for the category A, starting *immediately*. Thus, as a result the communication scenarios A1, A2 and A3 are apply.

In this scenario a German-wide coverage is necessary for the connection with the headquarters. At the operation scene coverage up to a radius of 1km is required. A data rate of 2Mbit/s is needed (only one simultaneous communication link), whereas this data rate is also needed for

the uplink. The connection links should be full-duplex. The vehicles are positioned stationary during the usage of the service.

This service is classified as *important*. The service has to be available at locations where control stations are reasonable (highways, cities, etc.) and at locations that show a typical coverage of the cellular radio network. In terms of time delays are acceptable, and a typical availability of the public land mobile network is sufficient. A call setup should be a matter of seconds, and the signal delay must short. The data are sensitive and must be encrypted. Public networks can be used.

Initial evaluation

For the communication with the headquarters the scenario 20.2 requires the deployment of a new nationwide network because the needed uplink data rate of 2Mbit/s cannot be provided by current networks. The communication between the vehicles at the operation scene can be realized with an ad hoc technology operating in the GHz-band (e.g., 5.15 – 5.25GHz).

6 Analysis of the interviews

This chapter contains the analysis of the information, which has been collected together with the PPDR agencies during the interviews. It will be started with a statistical analysis, followed by the determination of the bandwidth requirements of the respective Public Safety Agencies as well as the total bandwidth requirements. Finally the frequency demand for deploying the required communication technologies will be derived.

6.1 Statistic Analysis

The statistic analysis should illustrate tabularly as well as graphically a summary of the information collected during the interviews and derive there from first key results. For this purpose the following aspects have been analysed:

- Relevance of the respective communication scenarios
- Required technologies for the respective communication scenarios
- Required availability of the respective communication scenarios
- Bandwidth requirement versus operation category for the respective communication scenarios
- Coverage range versus operation category for the respective communication scenarios
- Required timely availability of the communication technologies necessary for the respective communication scenarios
- Communication technology versus relevance for the respective communication scenarios
- Bandwidth versus coverage range for the respective communication scenarios

6.1.1 Relevance of the scenarios

Concerning the relevance of the respective communication scenarios it has been differentiated between mission critical, important or desirable. Mission critical means here, that in case of a failure of the respective communication scenario life is immediately in danger.

In case different relevancies have been collected for the same communication scenario for different operational categories, the more critical relevance has been assigned to the respective communication scenario.

Mission Critical	50
Important	25
Desirable	2
Not specified	1

Table 6-1: Relevance of the different communication scenarios (number of replies)

Table 6-1 as well as Figure 6-1 show the analysis of the relevance of the respective communication scenarios. This illustrates, that nearly 75% of the communication scenarios are considered as „Mission Critical", that is, there failure would directly put life in danger.

Consequently for these communication scenarios the usage of public communication networks, which are shared with commercial users, has to be avoided due to safety aspects. The operation of these public networks is not under control of PPDR agencies; therefore an overloading by commercial users, resulting in a possible unavailability for PPDR agencies and consequently a failure of the respective communication scenarios cannot be avoided. Many PPDR agencies did already experience situations with an overload of the cellular networks by commercial users, specifically during major disasters, demonstrations and mass events.

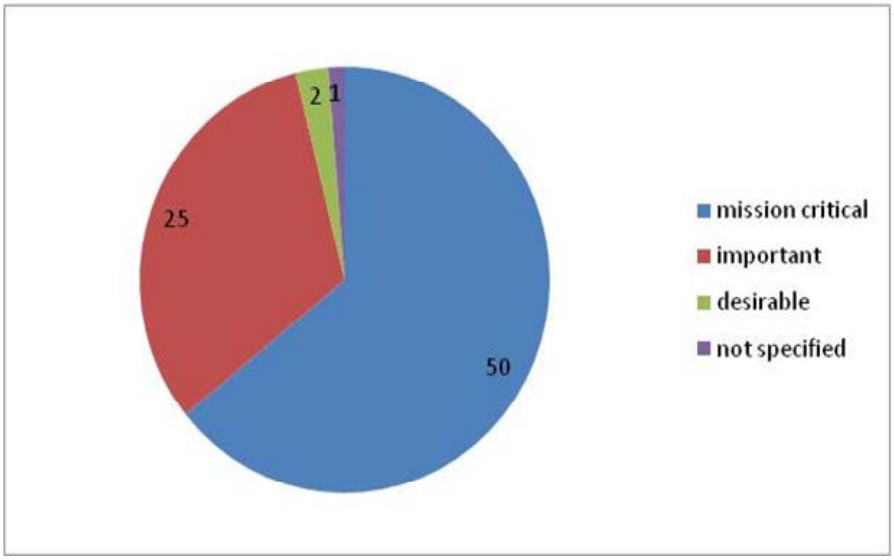

Figure 6-1: Relevance of the different communication scenarios (number of replies)

6.1.2 Required technologies

In order to fulfil the requirements for the communication scenarios, which have been determined together with the PPDR agencies within interviews, several suitable existing and emerging communication technologies have been identified.

To fulfil the requirements of some communication scenarios sometimes more than a single communication technology is required. In this case several communication technologies have been considered within the statistical analysis.

Specifically satellite communication has been considered suitable for scenarios with requirements for directional radio links, e.g. in case classical directional radio link systems do not provide sufficient range, as well as for scenarios with the requirement to provide coverage for whole areas, e.g. for allowing worldwide a data base access as it is possible using BGAN terminals.

Very specific and partly proprietary required technologies, such as remote triggering of blasting compositions or maritime radio, have been collected in an own category “Other technologies”.

Table 6-2 and Figure 6-2 illustrate the analysis of the communication technologies required for the respective communication scenarios. Obviously not all requirements from several communication scenarios can be fulfilled with a single communication technology, but a combination of different communication technologies is necessary. This combination comprises for example

- technologies for a car-to-car and a car-to-infrastructure communication like IEEE 802.11p, used e.g. for the control of traffic lights from approaching fire trucks,

- WLAN, used e.g. for the wireless connection of devices within vehicles,
- technologies for the flexible and infrastructure independent ad-hoc communication within the operational area, deployed in the 5 GHz frequency band, and used for command and control systems,
- technologies for the temporarily wireless inhouse coverage of buildings, deployed in the lower and middle MHz band, and used e.g. for telemetry applications,
- technologies of emerging cellular networks like LTE, used e.g. for the connection of police car to the central command centre,
- satellite links, used e.g. for the worldwide access of data bases as possible by using for example BGAN terminals, or
- further special technologies, used e.g. for a remote triggering of blasting compositions.

802.11p	**1**
WLAN	**3**
ad-hoc 5 GHz	**21**
indoor radio MHz	**11**
LTE	**34**
radio link / satellite	**16**
other	**13**

Table 6-2: Required technologies for fulfilling communication demand (number of replies)

It is also obvious, that about one third of the requirements of all communication scenarios could be fulfilled by an area-wide broadband cellular network, such as planned with LTE.

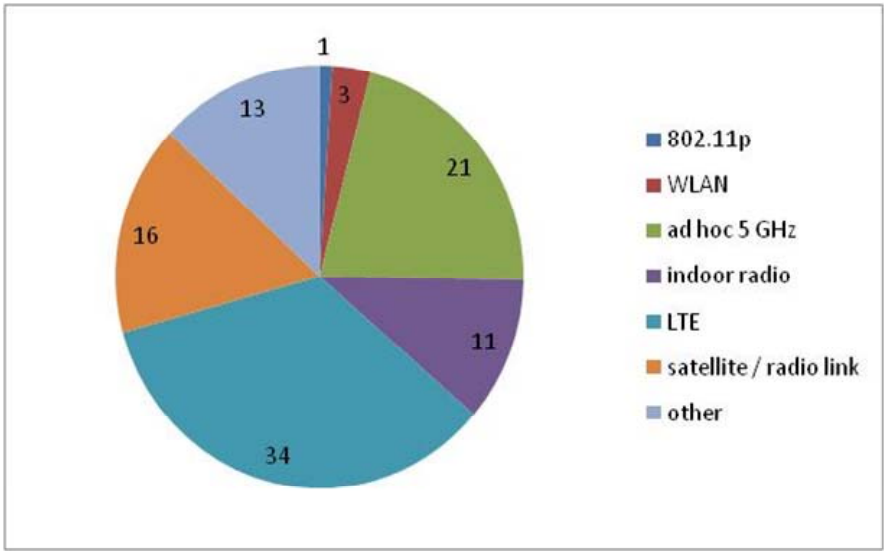

Figure 6-2: Required technologies for fulfilling communication demand (number of replies)

It becomes also clear, that the number of requirements for specific, partly proprietary communication technologies deployed in specific frequency bands sums up to more than 10 % and therefore is not negligible.

6.1.3 Availability requirements

Concerning the availability of the communication technologies suitable for the respective communication scenarios it has been differentiated between High and Normal.

In case depending from the operation categories different availability requirements have been assigned to a single communication scenario, the respective communication scenario has been assigned to the highest availability requirement.

high	69
normal	9
not specified	0

Table 6-3: Availability requirements for communication solution (number of replies)

Table 6-3 and Figure 6-3 illustrate the analysis of the availability requirements to the communication networks suitable for the respective communication scenarios.

Here it has to be outlined, that for nearly 90% of the communication scenarios a suitable communication network has to be highly available. This means that for these communication scenarios the usage of public networks, which are shared with commercial users, is not possible due to safety aspects.

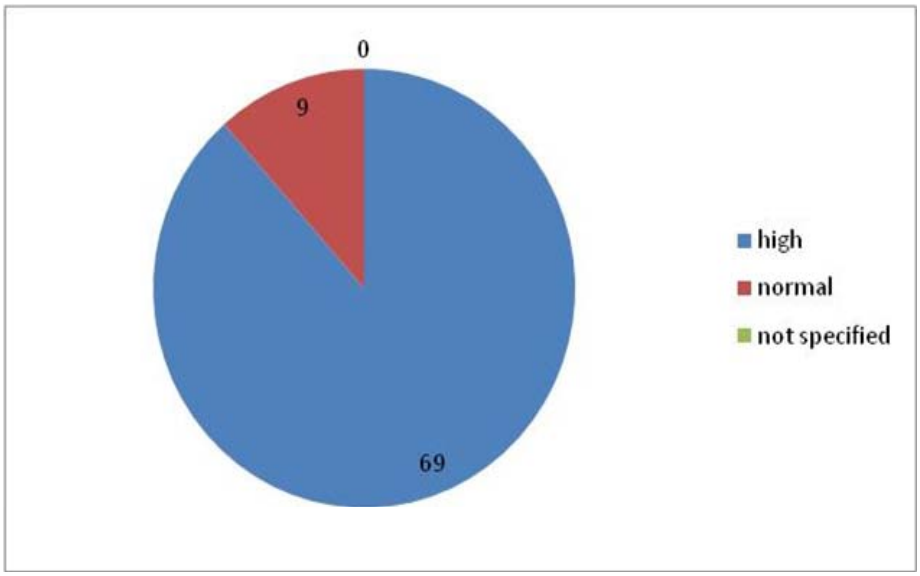

Figure 6-3: Availability requirements for communication solution (number of replies)

The operation of these public networks is not under control of PPDR agencies; therefore an overloading by commercial users, resulting in a possible unavailability for PPDR agencies and consequently a failure of the respective communication scenarios cannot be avoided. The required high availability cannot be ensured.

6.1.4 Bandwidth requirements versus operation category

Furthermore it has been statistically analysed, which bandwidth requirement the respective communication scenarios have in the 3 operation categories, “normal operation of the PPDR agencies” (category A), “demonstration and cultural or sport mass events” (category B) and “natural and other major disasters” (category C). Here it has been differentiated between bandwidth requirements of less than 10 kbit/s, less than 100 kbit/s, less than 1 Mbit/s, less than 5 Mbit/s, less than 10 Mbit/s and equal or more than 10 Mbit/s. Each communication scenario have been assigned to a single bandwidth requirement only, not to several ones, that is, a communication scenario with a bandwidth requirement of less than 10 kbit/s has only be assigned to “less than 10 kbit/s”, but not simultaneously to “less than 100 kbit/s”, “less than 1 Mbit/s”, … .

In case different bandwidth requirements have been gathered for a certain communication scenario for different communication technologies, e.g. one bandwidth requirement for the on-site coverage of the operation area and another one for the connection of the operation area with a remote control centre, all different bandwidth requirements have been gathered separately. In case different bandwidth requirements have been collected for the different directions of a communication technology, e.g. for up- and downlink of a satellite connection, the direction with the “highest” bandwidth requirement has been gathered.

	< 10 kbit/s	< 100 kbit/s	< 1 Mbit/s	< 5 Mbit/s	< 10 Mbit/s	≥ 10 Mbit/s
normal (A)	3	3	10	22	11	26
demonstration (B)	2	4	7	11	7	28
disaster (C)	2	4	7	19	7	30

Table 6-4: Bandwidth requirements for different operation categories (number of replies)

Table 6-4 and Figure 6-4 illustrate the analysis of the bandwidth requirements for the respective communication scenarios for the each of the 3 operation categories.

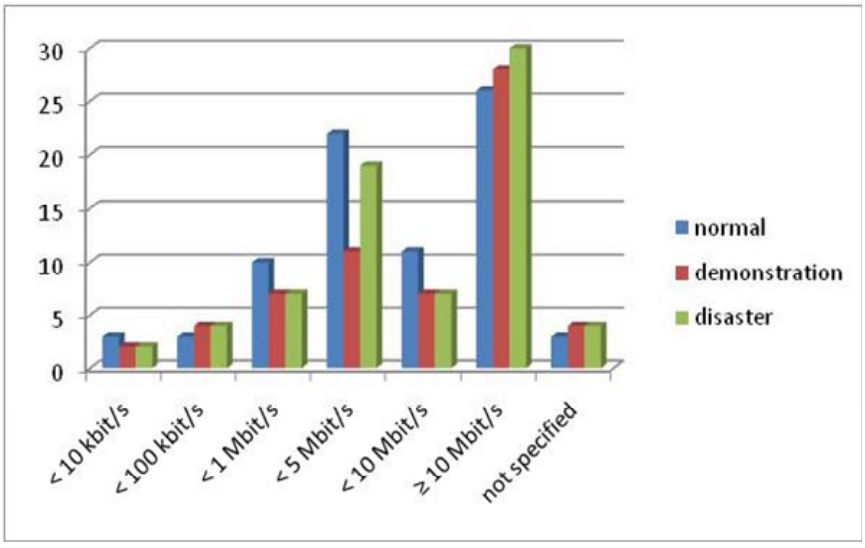

Figure 6-4: Bandwidth requirements for different operation categories (number of replies)

First the strong requirements for broadband communication become apparent. Nearly 65% of all communication scenarios have a bandwidth requirement of more than 1 Mbit/s, over 40% even a bandwidth requirement of more than 10 Mbit/s. This high number of broadband requirements is on the one hand side certainly caused by the fact, that all applications, which can be deployed within the currently introduced TETRA system, have been explicitely excluded from this study; on the other hand these results clearly outline the high demand for broadband communication.

Furthermore the results show, that for major disasters (category C) the bandwidth requirements are not significantly higher than for the normal operation (category A). One reason for this is that partly different applications are used for the different operation categories. Furthermore for larger operations the operation area most times is subdivided within smaller operation sections. The bandwidth requirements within such operation sections of major disasters are partly comparable with the requirements of a normal operation.

6.1.5 Range versus operation category

For the separate communication scenarios it also has been statistically analysed for the 3 operation categories “normal operation of the PPDR agencies” (category A), “demonstration and cultural or sport mass events” (category B) and “natural and other major disasters” (category C), which distances (for directional radio links) are required respectively which areas (for area coverage) have to be covered.

The statistical analysis has been done separately for directional radio links and area coverage. For the range either the distance of the directional radio link has been used, or the radius of the covered area. The requirements for a certain range have been distinguished between less than 500 m, less than 1 km, less than 5 km, less than 10 km, and equal or more than 10 km. Each communication scenario have been assigned to a single range requirement only, not to several ones, that is, a communication scenario with a range requirement of less than 500 m has only be assigned to “less than 500 m”, but not simultaneously to “less than 1 km”, “less than 5 km”, … .

For directional radio links satellite connections only have been gathered if they are used for realising a fixed point-to-point connection, such as the connection of base stations or relay stations.

	< 500 m	< 1 km	< 5 km	< 10 km	≥ 10 km	not specified
normal (A)	0	0	0	0	11	0
demonstration (B)	0	0	0	0	8	0
disaster (C)	0	0	0	0	10	0

Table 6-5: Required distance of directional radio links for different operation categories (number of replies)

Table 6-5 and Figure 6-5 clearly show, that directional radio links are required only for distances of more than 10 km.

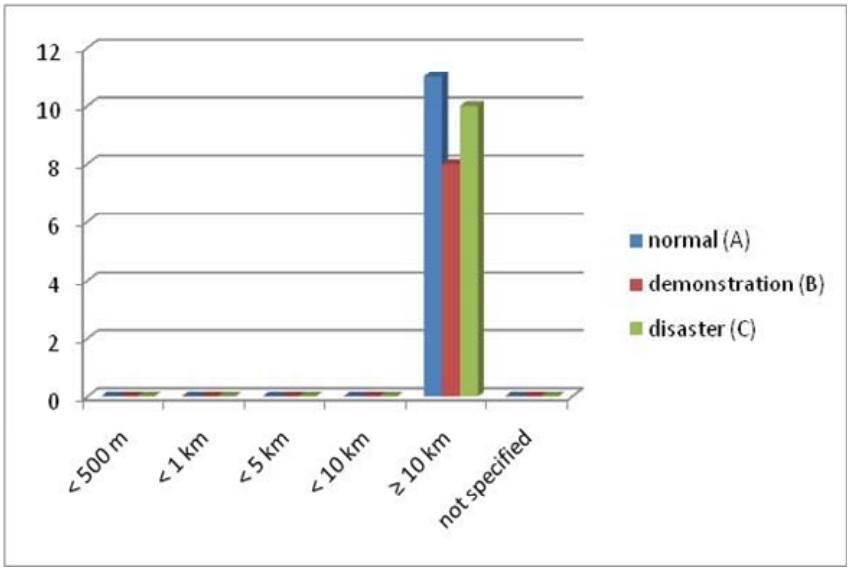

Figure 6-5: Required distance of directional radio links for different operation categories (number of replies)

As already mentioned above in case of an area coverage the radius of the area to be covered has been taken as range. Satellite connections have only been gathered here, if they are used for a communication scenario with the requirement to cover an area, such as the possibility of a worldwide data transmission using e.g. BGAN terminals.

	< 500 m	< 1 km	< 5 km	< 10 km	≥ 10 km	not specified
normal (A)	15	7	5	0	40	3
demonstration (B)	4	4	11	0	35	3
disaster (C)	7	6	8	0	40	3

Table 6-6: Radius of area to be covered for different operation categories (number of replies)

Table 6-6 and Figure 6-6 outline that either small areas with a radius less than 5 km have to be covered, or large areas with a radius of more than 10 km. Specifically the coverage of areas with a radius of more than 10 km have been required by more than 60% of the communication scenarios. For this range for example emerging cellular technologies such as LTE could be suitable, but also satellite communication.

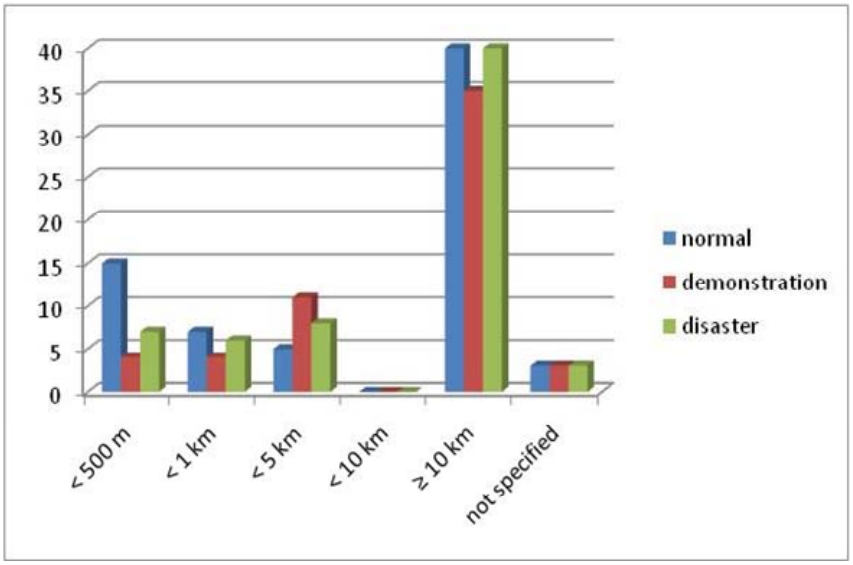

Figure 6-6: Radius of area to be covered for different operation categories (number of replies)

6.1.6 Technology versus timely availability

The statistical analysis examined also when the communication technologies suitable to address the requirements of the respective communication scenarios should be available. This point in time is based on the strategic planning of the PPDR agencies, that is, when they plan to make operational use of the applications of a certain communication scenario. Here the requirements for a timely availability have been separated in “immediately”, “latest in 2012”, “latest in 2014”, and “later than 2014”. Each communication scenario have been assigned to a single timely availability requirement only, not to several ones, that is, a communication scenario with a timely availability requirement of “immediately” has only be assigned to “immediately”, but not simultaneously to “latest in 2012”, “latest in 2014”, … .

	immediately	*≤ 2012*	*≤ 2014*	*>2014*
802.11p	1	0	0	0
WLAN	3	0	0	0
ad-hoc 5 GHz	20	0	0	1
indoor radio MHz	11	0	0	0
LTE	30	0	1	1
satellite / radio link	14	1	1	0
other	12	0	0	0

Table 6-7: Timely availability of the respective communication technologies (number of replies)

The differentiation of the timely intervals has been mainly based on the results of the interviews.

Table 6-7 and Figure 6-7 show, that even if the frequency planning work cannot implement major results of the study before 2015, the PPDR agencies nevertheless would benefit already

earlier from possible new frequencies required for the various communication technologies. Nearly 95% of the communication scenario would require suitable communication technologies immediately. Thereby nearly no difference is recognizable between the timely availability requirements of different communication technologies.

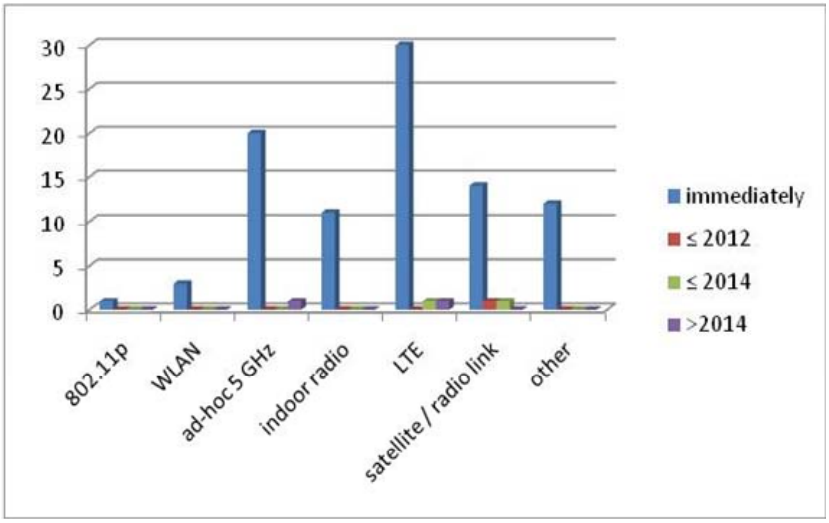

Figure 6-7: Timely availability of the respective communication technologies (number of replies)

6.1.7 Technology versus relevance

The statistical analysis further comprises which communication technologies will be used with which relevance in the respective communication scenarios, that is, how relevant is finally the communication technology itself.

In case for a single communication scenario different relevances have been assigned in different operation categories (A, B, C) or different operation conditions, the scenario has been gathered with the “most critical” relevance.

	mission critical	*important*	*desirable*
802.11p	0	1	0
WLAN	2	0	1
ad-hoc 5 GHz	13	7	1
indoor radio MHz	11	1	0
LTE	17	15	0
satellite / radio link	11	4	0
other	10	2	0

Table 6-8: Required communication technologies for operation scenarios with different relevance (number of replies)

Table 6-8 and Figure 6-8 outline for example, that specifically communication technologies for the temporariy inhous radio coverage of buildings in the lower and middle MHz range will be deployed mainly in communication scenarios, which are considered as mission critical.

Furthermore it becomes clear, that nearly 50% of the communication scenarios, which could benefit from emerging cellular communication systems such as LTE, are not considered as mission critical. It should be noted here, that from these communication scenarios still a majority requires a high availability of the communication network, which cannot be ensured for PPDR agencies in today's cellular communication networks.

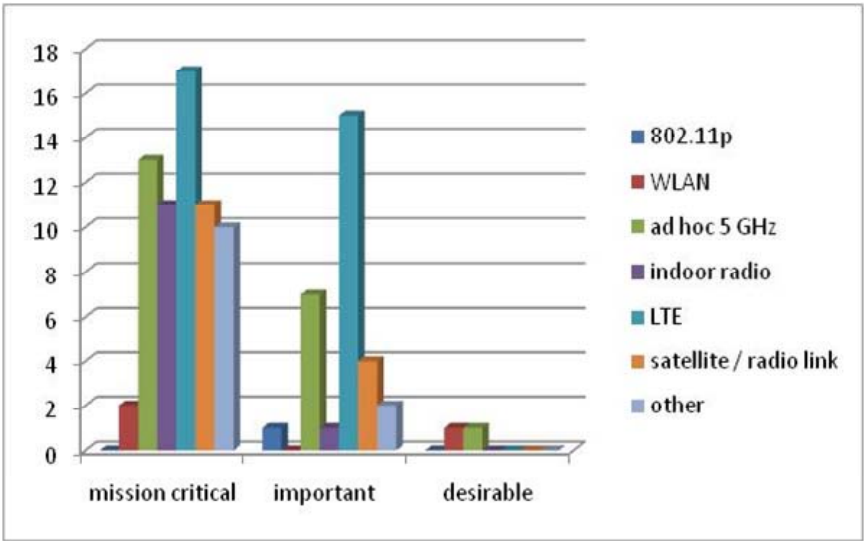

Figure 6-8: Required communication technologies for operation scenarios with different relevance (number of replies)

6.1.8 Bandwidth versus range

Finally it has been statistically analysed, which bandwidth requirements have been identified for the respective distances (in case of directional radio links) and areas (in case of area coverage). Here the requirements for a certain distance of a directional radio link respectively for a certain radius of an area to be covered have been distinguished again between less than 500 m, less than 1 km, less than 5 km, less than 10 km, and equal or more than 10 km. The bandwidth requirements have been differentiated again between less than 10 kbit/s, less than 100 kbit/s, less than 1 Mbit/s, less than 5 Mbit/s, less than 10 Mbit/s and equal or more than 10 Mbit/s.

	< 500 m	*< 1 km*	*< 5 km*	*< 10 km*	*≥ 10 km*
< 10 kbit/s	0	1	0	0	1
< 100 kbit/s	1	1	0	0	1
< 1 Mbit/s	1	1	0	0	6
< 5 Mbit/s	4	1	2	0	15
< 10 Mbit/s	1	1	2	0	9
≥ 10 Mbit/s	2	3	5	0	22

Table 6-9: Bandwidth requirements for different ranges (number of replies)

Table 6-9 and Figure 6-9 outline, that more than 57% of the communication scenarios require a bandwidth of more than 1 Mbit/s over a range of more than 10 km. This underlines the

requirement of long distance broadband communication, which could e.g. be fulfilled by emerging cellular technologies like LTE.

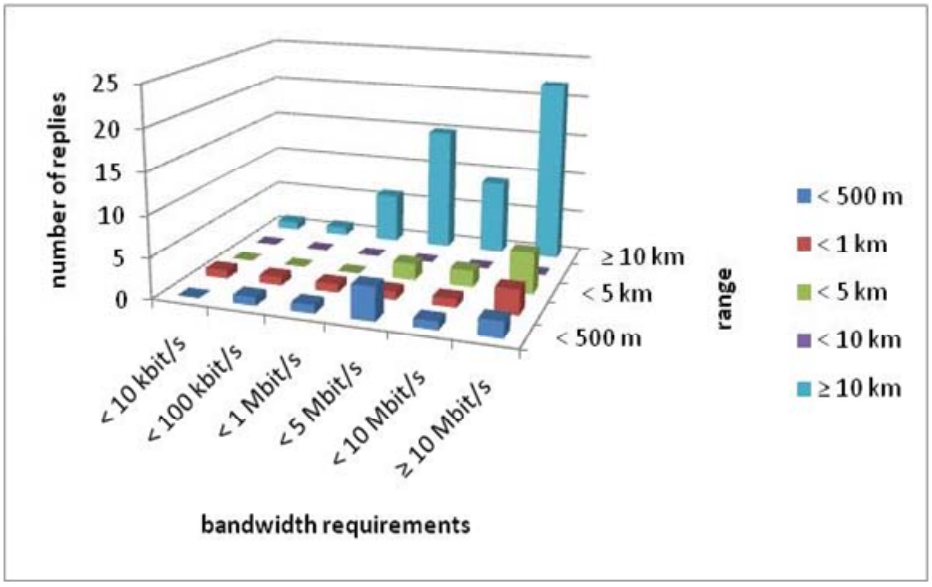

Figure 6-9: Bandwidth requirements for different ranges (number of replies)

6.2 Determination of the bandwidth requirements for the PPDR scenarios

After the statictical analysis in a next step the bandwidth requirements will be determined.

Nach der statistischen Auswertung werden in einem nächsten Schritt die Bandbreitenanforderungen ermittelt.

6.2.1 Procedure applied for the determination of the overall bandwidth requirements

For the determination of the overall bandwidth requirements the following steps are followed:

- **Step 1: Identification of suitable technologies:** For fulfilling the communication needs commercially available technologies operated by the PPDR agencies should be used. This would ensure the required availability and reliability. Furthermore this could be economically interesting, as external provider costs are avoided. In this analysis current and emerging technologies will be considered, such as ad-hoc networks, WLAN, LTE, satellite, indoor radio, IEEE 802.11p, or directional radio links (see 6.2.2.1). The identification of technologies, which could be used for a certain communication scenario, has already been done within chapter 5, where at the end of the description of each scenario a first analysis of suitable communication technologies has been performed. Thereby the interview results have been considered, such as the bandwidth requirement, the size of the area to be covered respectively the distance between communication partners, the mobility of the users, the necessity to have a inhouse coverage of buildings, etc. .
- **Step 2: Determination of the theoretically maximal overall bandwidth requirement per category (A, B, and C) per technology:** The bandwidth requirements per communication scenario have been gathered within the interviews. Thereby also suitable communication technologies for the respective scenario have been identified. Now the overall bandwidth requirement per communication technology has to be determined. As the communication scenarios of a single PPDR agency as well as the ones of different PPDR agencies partly take place at the same time and at the same location, the respective bandwidth requirements per communication technology have to be added up. Thereby an addition is only been done for those scenarios, which can take place from a tactical and operational point of view at the same time and at the same place. The addition will first be done for each of the categories (A, B, and C) separately.
- **Step 3: Determination of the highest, theoretically maximal overall bandwidth requirement of all categories:** A communication system based on a certain communication technology has to be dimensioned in a way, that it is able to fulfill the highest, theoretically maximal overall bandwidth requirement of all categories (A, B, and C). Therefore this highest value will be used for further analysis.
- **Step 4: Adjustment of the highest, theoretically maximal overall bandwidth requirement based on operational priorisation of the single requirements:** Within this step further conditions based on operational priorisation will be considered. This happens in three steps:

    - Step 1: First only those scenarios are considered for bandwidth requirement addition, which have been classified as “mission critical”.
    - Step 2: After that, from the remaining scenarios only those are considered for bandwidth requirement addition, which are related to realtime applications, e.g.

video, realtime data transmission, etc. – the other non realtime application will be supported as “best effort”.

- Step 3: In this step all scenarios will be removed, which are only deployed for redundancy reasons.

6.2.2 Result of the determination of the overall bandwidth requirements

6.2.2.1 Technologies

Based on the analysis of the interview results the following communication technologies have been identified for fulfilling the bandwidth requirements:

- **Ad hoc networking within the 5 GHz band:** Ad hoc networks, in which the communication nodes automatically (ad hoc) connect to each other via radio links, can be used especially for broadband communication within the operation area. For this purpose CEPT reserved the frequency band 5,15 – 5,25 GHz for so called Broadband Disaster Relief (BBDR) applications in Europe. ETSI specified within EN 302 625 the respective node behavior. Within this frequency band for example an amplified version of the IEEE 802.11a standard could be deployed.
- **WLAN technology based on IEEE 802.11:** WLAN technology (IEEE 802.11 is suitable for a broadband connection of communication end devices with a WLAN access point in a kind of a star topology. This way the end devices could communicate with each other wirelessly or can be connected wirelessly to a Wide Area Network.
- **LTE (Long Term Evolution) cellular network:** Many PPDR scenarios require the coverage of an area of a size, which cannot be done easily with ad hoc networking technology in the 5 GHz band. Cellular technologies such as GPRS or UMTS, which are currently deployed within commercial networks, do not provide the required data rates. Also the partly available HSPA technology only partly fulfills the bandwidth requirements. Therefore it is advantageous to rely directly on the new cellular technology Long Term Evolution (LTE), which will offer much higher data rates than today’s cellular networks.
- **Satellite:** In case the connection of communication partners has to be done over large distances and independently from any fixed infrastructure, satellite technology can be used. Furthermore satellite technology is also used as redundancy for terrestrial fiber links.
- **Indoor radio:** Some scenarios have to support applications, which require an inhouse coverage of buildings, such as the control of respiratory protection devices or communication inside buildings. A communication technology supporting this will be called in the following as indoor radio. Thereby it is desirable to make use of a very low frequency in order to allow radio wave propagation through walls and ceilings.
- **Car-to-car communication using IEEE 802.11p:** In the context of one scenario the communication between operation vehicles and traffic control systems has been requested. For such a communication the standard IEEE 802.11p has been developed.
- **Directional radio links:** Many scenarios require point-to-point connections using directional radio links, such as for the connection of different operation sites over a large distance. Here the bandwidth requirements often havn’t provided in Mbit/s, but in the number of required directional radio link channels. Therefore for the determination of the overall bandwidth requirements the number of directional radio link channels will be added up.
- **Directional radio links in the 14 GHz band:** Within some scenarios explicitely directional radio link channels in the 14 GHz band for video transmission have been requested. These requirements have been added up separately.

6.2.2.2 Theoretically maximal bandwidth requirements

Table 6-10 lists the theoretically maximal bandwidth requirements per operation category per technology (see step 2 in 6.2.1). Furthermore for each communication technology the highest bandwidth requirement is marked in red (see step 3 in 6.2.1).

technology	normal (A)	demo (B)	disaster (C)
ad hoc 5 GHz (in Mbit/s)	*239*	*312*	*276*
WLAN 802.11 (in Mbit/s)	*35*	*31*	*31*
LTE downlink (in Mbit/s)	*355*	*611*	*613*
LTE uplink (in Mbit/s)	*388*	*651*	*622*
satellite (bidirect., in MBit/s)	*360,5*	*260,5*	*260,5*
indoor radio (in Mbit(s)	*9,6*	*4,6*	*5,6*
802.11p (in Mbit/s)	*0,1*	*0,1*	*0,1*

technology	normal (A)	demo (B)	disaster (C)
directional radio (channels)	*25*	*40*	*27*
directional radio for video in 14 GHz (channels)	*15*	*20*	*20*

Table 6-10: overall bandwidth requirements of the different categories

6.2.2.3 Overall bandwidth requirements considering operational priorisations

As described within step 4 of chapter 6.2.1 operational priorisations will be considered to reduce the overall bandwidth requirements. The results of this consideration are listed in Table 6-11. In this table the 4 columns have the following meaning:

- **Maximal:** The values of this column are the theoretically maximal bandwidth requirements of all categories (red marked number of Table 6-10).
- **Mission critical:** The values of this column result from the consideration of only those scenarios, which have been classified as “mission critical”.
- **Realtime:** Within this column bandwidth requirements are added up only for those scenarios, which have been classified as “mission critical” and which are related to realtime applications.
- **No redundancy:** Within this column bandwidth requirements are added up only for those scenarios, which have been classified as “mission critical”, which are related to realtime applications, and which are not only deployed for redundancy reasons.

technology	maximal	mission critical	realtime	no redundancy
ad hoc 5 GHz (in Mbit/s)	312	189	189	178
WLAN 802.11 (in Mbit/s)	35	15	15	0
LTE downlink (in Mbit/s)	613	267	197	187
LTE uplink (in Mbit/s)	651	335	265	255
satellite (bidirec., in Mbit/s)	360,5	260,5	260,5	0,5
indoor radio (in Mbit/s)	9,6	9,6	9,6	9,6
802.11p (in Mbit/s)	0,1	0	0	0
directional radio (channels)	40	39	39	39
Direct. radio 14 GHz (cha.)	20	20	20	20

Table 6-11: bandwidth requirement considering operational priorisations

6.2.2.4 Important operational and tactical conditions

For the determination of the bandwidth requirements of single scenarios respectively the determination of the maximal overall bandwidth requirements within chapter 6.2.2.2 some important operational and tactical conditions had to be considered. These conditions are listed in the following.

- The Federal Office for Freight Transport (BAG) will not perform their control task at the same locations and at the same time of demonstrations, mass events, natural disasters or other major disasters. Therefore the bandwidth requirements of the BAG will not be considered for categories B and C.
- At the same time at a single operation site / operation segment respectively within a single radio cell typically either a professional fire brigade, a company fire brigade, a voluntary fire brigade or the fire and disaster prevention agencies of a county is active. Therefore for comparable communication scenarios the highest bandwidth requirements from all these agencies will be considered for further analysis. Bandwidth requirements for communication scenarios, which are requested only from a single agency, will be added.
- Different state polices are typically not at the same time at the same operation site / operation segment respectively the same radio cell. Therefore for comparable communication scenarios the highest bandwidth requirements from all these state polices will be considered for further analysis. Bandwidth requirements for communication scenarios, which are requested only from a single state police, will be added.
- The following PPDR agencies from the police can be present at the same time at the same operation site and communicate:

  - a state police
  - a Special Police Force / Mobile Task Force
  - Federal Criminal Police Office
  - Federal Police
  - further not specified PPDR agencies

- The number of vehicles from the rescue service of a professional fire brigade, which could be simultaneously within the same radio cell and which are transmitting simultaneously video to the hospital, will be maximal 2 during normal operation and maximal 10 during major events and disasters (*it should be noted, that during the interviews for the greater Berlin area maximal 10 during normal operation and maximal 50 during major events and disasters have been required*).
- Only 2 rescue services will be considered to be at the same time at the same operation, e.g. the German Red Cross and the rescue service of the local professional fire brigade.
- In case of alterting of rescue forces during normal operations, demonstrations and mass events (categories A and B) maximal one person to be alerted per radio cell is assumed, during disasters (category C) maximal 2 persons to be alerted per radio cell are assumed.
- Maximal 3 NBC detection vehicles are during operation simultaneously within the same radio cell.
- Maximal 5 mobile command vehicles are during operation of fire brigades simultaneously within the same radio cell.
- In case only a required dulpex transmission rate is given for the communication between central command center an operation site, without further detailing into required downlink and uplink capacity, a relation from 4:1 (downlink:uplink) is assumed.
- For some communication scenarios a minimal bandwidth of 4 Mbit/s for video transmission over directional radio link channels in the 14 GHz band has been requested, desirable would be the support of HD video signal transmission (4-20 Mbit/s). For these cases a single directional radio link channel per video transmission is assumed.
- The police of the state of North Rhine-Westphalia requested the connection of fixed installed cameras to the police network. A precise number of cameras per operation site wasn't possible to obtain. It has been assumed, that not more than 5 cameras are simultaneously present at the same operation site.
- The police of the state of North Rhine-Westphalia requested the connection of sensors to the police network. It wasn't possible to specify a precise number of sensors per operation site. It has been assumed, that not more than 200 sensors are simultaneously present at the same operation site.
- The police of the state of North Rhine-Westphalia requested for category B and C 60 communication points (mobile cameras, drones, mobile command centres, ...) per operation site, which communicate with each other and with the central command centre. It has been assumed, that not more than 20 of them are simultaneously within the same radio cell.
- The Federal Police requested wireless voice communication as addition respectively redundancy to the currently deployed TETRA system. Per voice connection 64 kbit/s

have been requested, however, it wasn't possible to specify in detail the voice connections per operation site. For the determination of the bandwidth requirements it has been assumed, that per radio cell not more than 4 Mbit/s will be needed for voice communication, which would allow 64 simultaneous voice connections.

- The Federal Police requested data transmission between persons and vehicles at the operation site respectively between the operation site and the command centre. It wasn't possible to specify in detail the number of simultaneous connections for data transmission. For the determination of the bandwidth requirements it has been assumed, that not more than maximal 20 simultaneous connections per radio cell are required.
- For all operations in foreign countries the bandwidth requirements will not be added to the overall bandwidth requirements. Compared to operations in the home country only a small part of the PPDR agencies will be active in operations in foreign countries. Furthermore the reservation of worldwide frequencies for this purpose will most likely be difficult.
- The required area-wide network will be multicast capable, that is, data, which have to be distributed to several receivers, will have to be sent per radio cell only one time.

6.3 Frequency spectrum requirements of different technologies

6.3.1 Procedure for the derivation of the frequency spectrum requirement per technology

The relation between data rate (in bit/s) and the needed frequency requirement (in Hz) of a certain technology depends on many different factors, e.g.

- modulation scheme
- medium access control
- error correcting code
- overhead of different layers

In order to ensure a realistic approach for the evaluation of the frequency spectrum requirements the relation between data rate and frequency spectrum requirement was derived from the experience based on network operation or on pilot tests.

Furthermore, also new trends concerning further technology developments were considered and analyzed to be able to assess their future influence (until 2015). Examples of further technology developments are LTE Advanced (release 10) and the usage of IEEE 802.11n for ad hoc networks.

Similar to the overall bandwidth requirements also the overall frequency spectrum requirements were derived step-by-step. First the overall frequency spectrum requirements (per technology) were determined for the theoretically maximal overall bandwidth requirements. Then the overall frequency spectrum requirements were derived by considering operational priorities (“mission critical”, need for real-time, no redundancy).

6.3.2 Ad hoc technologies operating in the 5 GHz band

IEEE 802.11a:

As already described in chapter 6.2.2.1, in Europe the frequency range 5.15 - 5.25 GHz was allocated by the CEPT for so called broadband disaster relief (BBDR) applications. This frequency range can be used for the realisation of ad hoc networks by using an amplified variant of the IEEE 802.11a standard.

WLAN 802.11a uses 20 MHz-channels. Due to the required reserves for the edges of the spectrum in the range 5.15 - 5.25 GHz up to 3 non-overlapping channels can be realized. Dependent on the link quality and accordingly the signal-to-noise ratio different modulation schemes are possible (BPSK, QPSK, 16QAM, or 64QAM).

If using 64QAM and a forward error correction (FEC) of ¾ the resulting maximum data rate (on layer 2) is 54 Mbit/s. Measurements done by the IABG show that via a 802.11a link with a data rate of 54 Mbit/s the transmission of an IP user data rate of up to 28 Mbit/s is possible.

Ad hoc networks support relay functionality. If a direct link between sender and receiver is not possible (e.g. due to a high distance or shielded areas) data can be transmitted via a relay that is linked to the sender as well as to the receiver.

Such a connection can also be realized with more relays. But a relay has to send and receive data simultaneously, which results in a reduction of the maximum transmittable data rate.

Experiences based on field trials by the IABG show that the maximum IP user data rate decreases by the factor 2.2 if using one relay and by the factor 3.2 if using 2 relays. To evaluate the frequency requirement the assumption was made that on average 4 nodes are linked (thus 2 relays). With this condition a data rate of **9 Mbit/s** can be achieved in a **20 MHz**-channel.

IEEE 802.11n:

In order to provide a higher data rate compared to 802.11a/g the standard IEEE 802.11n was designed. In future, this standard might be used for the realization of ad hoc networks operating in the 5 GHz band instead of 802.11a. But the following aspect has to be considered:

Current WLAN-products and drivers do not support 802.11n operating in the ad hoc mode but only in the infrastructure mode. If setting the mode to ad hoc the used standard is often switched to 802.11a/g. Probably this effect will change in future. Thus, there is no experience available. Therefore only assumptions can be considered.

802.11n can be used in the 2.4 GHz-band as well as in the 5 GHz-band. Here, the channel bandwidth is up to 40 MHz. 802.11n achieves at the maximum 150 Mbit/s per data stream (data rate on layer 2). But caused by the usage of MIMO-technology (Multiple In Multiple Out) multiple (up to 4) data streams can be transmitted simultaneously and combined at the receiver if operating with multiple transmitting and receiving antennas (each up to 4). Thus, a data rate of 300 Mbit/s (on layer 2) with 2 spatially separated data streams and a data rate of 600 Mbit/s (on layer 2) with 4 spatially separated data streams is resulting (see [802.11n]).

Networkcomputing.de measured the performance of a Cisco Aironet 1250 with the result of 155 Mbit/s as TCP data rate at a channel bandwidth of 40MHz (see [NC]). According to the data sheet the Cisco Aironet 1250 supports up to 600 Mbit/s,

Assuming an average connection of 4 nodes (2 relays) the IP user data rate decreases by the factor 3.2 (as if using 802.11a) that results in a data rate of **48 Mbit/s** for one **40 MHz** channel.

6.3.3 WLAN-Technology 802.11

WLAN technology (infrastructure mode) is standardized according to IEEE 802.11a/b/g and operates in the frequency range of 2.4 GHz (802.11b/g) and 5 GHz (802.11a). The channel bandwidth in the 2.4 GHz band is 22 MHz (the channel spacing is only 5 MHz but the channels are overlapping). The channel bandwidth in the 5 GHz band is 20 MHz. The maximum data rate (layer 2) is 54 Mbit/s in the 2.4GHz band as well as in the 5 GHz band. According to measurements of the IABG up to 28 Mbit/s can be transmitted as IP user data. Thus, a data rate of **28 Mbit/s** per **20 MHz / 22 MHz** is considered for the evaluation of the frequency requirement.

6.3.4 LTE-Technology (Long Term Evolution)

As already described in chapter 6.2.2.1, many PPDR scenarios require a network with area-wide coverage that is based on a broadband mobile communication technology. Thus, in the following the 3GPP-standards Long Term Evolution (LTE) (Release 8) and LTE Advanced (Release 10) are considered. But it has to be noticed that in contrast to LTE (Release 8) experiences regarding LTE Advanced are hardly available.

LTE (Release 8):

LTE (Release 8) was defined and standardized as follow-up technology of UMTS by 3GPP (3rd Generation Partnership Project). The specification is finished. The literature gives many examples and documentations about LTE that sometimes even are contradictory. The following considerations are based on the references [3GPP], [Qualcomm], and [Ericsson].

In the following some technical details concerning LTE are listed:

- The downlink is based on OFDM (Orthogonal Frequency-Division Multiplex); the uplink is based on DFTS-OFDM that has a lower peak-to-average-power-ratio and thus is ideal for small end devices (handhelds).
- The separation of the downlink and the uplink can be realized by TDD or FDD.
- The channel bandwidth can be selected between 1.4, 3, 5, 10, 15, and 20MHz.
- As modulation schemes QPSK, 16QAM, or 64QAM are used.
- The transmitting frequency is not fixed.

Due to the usage of MIMO-technology (Multiple Input Multiple Output) with multiple transmitting and receiving antennas a spatial separation is possible by the usage of special MIMO-algorithms (e.g. „Virtual MIMO“). This approach is called Space Division Multiple Access (SDMA).

The following maximum data rates (peak data rates) on layer 2 are related to a channel bandwidth of 20MHz:

- in the downlink:
    - ♦ 150Mbps in the case of 2 transmitting and 2 receiving antennas (2x2)
    - ♦ 300Mbps in the case of 4 transmitting and 4 receiving antennas (4x4)
- in the uplink:
    - ♦ 75Mbps in the case of 1 transmitting and 2 receiving antennas (1x2)

Among others, the real data rate depends on the expansion stage of the network and also on the end device (the first end devices might support only 2x2). The used modulation scheme (QPSK, 16QAM, 64QAM) depends on the signal strength and accordingly the SNR-value.

First LTE tests were already done and the resulting data rates were published. In the following some of these tests are listed:

- **Nokia Siemens Networks:** Nokia Siemens Networks transmitted 160 Mbit/s in the downlink and 108 Mbit/s (2 x 54 Mbit/s) in the uplink during a test in May 2007. Here, 2 end devices were used that separated the data streams by SDMA with „Virtual MIMO“ (see [NSN]).
- **NTT DoCoMo:** NTT DoCoMo demonstrated a data rate of 250 Mbit/s in the downlink during a field test in March 2008 (see [NTT]).
- **T-Mobil:** T-Mobil installed a LTE test network in Innsbruck. There, 60 radio cells are realized (based on 3G-pattern). Huawei is the network supplier. Here, a data rate of 50 Mbit/s in the uplink as well as in the downlink is realized (see [T-Mobil]).

Concerning the frequency requirement a channel bandwidth of 20 MHz is used for the calculation. Due to the separation of the uplink and the downlink by the FDD-method 2 separate

20 MHz channels are necessary. According to [3GPP] here the theoretical maximum data rate is 300 Mbit/s in the downlink and 75 Mbit/s in the uplink. But to derive the frequency spectrum requirements these theoretical values cannot be used. Thus, the results of the real field trial of Nokia Siemens Networks (May 2007) are used. There a data rate **of 160 Mbit/s** in the **downlink** and **108 Mbit/s** in the **uplink** were achieved (each channel bandwidth **20 MHz)**.

LTE Advanced (Release 10):

In the meantime, LTE was further developed. The release 10 is called LTE Advanced. But the following aspect has to be considered:

Currently, LTE Advanced is in the development and specification phase. Thus, here only assumptions are possible and experiences are hardly available.

According to [3GPP IMT] the maximum data rate is 1 GBit/s in the downlink and 500 Mbit/s in the uplink. Concerning channel access different possibilities are discussed, e.g.

- **40 MHz in the uplink** and **80 MHz in the downlink** (FDD) (used for the following considerations) or
- 100 MHz in the uplink and the downlink (TDD)

Compared to LTE (release 8) the peak spectrum efficiency (bps / Hz) is higher by the factor 2 in the downlink and by the factor 4 in the uplink.

If multiplying the practical achieved data rate of the LTE test done by Nokia Siemens Networks (down 160 Mbit/s, up 108 Mbit/s) with these factors, the following data rates are resulting for LTE Advanced:

- **Downlink: 320 Mbit/s**
- **Uplink: 432 Mbit/s**

6.3.5 Satellite technology

Different satellite technologies are existing, e.g.

- VSAT
- SCPC (Single Channel Per Carrier)
- DVB-S/RCS

The frequency spectrum requirements in MHz per Mbit/s depend on the used technology, the dimension of the antenna, the modulation scheme, the location, and the used satellite. To derive the frequency spectrum requirements an example is considered in which a satellite station in Berlin is connected to a ground station in Munich via an appropriate satellite (located over Central Europe). The following cases are to be differentiated:

- The usage of a 3-5m-antenna at the operation scene and the transmission to a hub-station per SCPC simplex with 8-PSK results in a data rate of 1 Mbit/s per 300 kHz.
- The usage of a 1.2m-antenna at the operation scene and the transmission to a hub-station per SCPC simplex with 8-PSK results in a data rate of 1 Mbit/s per 500 kHz

The antenna dimension is not known for the scenarios. Thus, an average data rate of 1Mbit/s per 400 kHz is assumed (simplex). As a consequence, a bandwidth of **0,8 MHz** per **1 Mbit/s** is necessary for duplex operation.

6.3.6 In-house radio

Many applications require in-house coverage like telemetry applications (e.g. monitoring of respiratory protection devices or sensors), voice communication inside buildings, or data applications inside buildings.

If operating at high frequencies the in-house coverage is difficult to achieve. Thus, the lower MHz band (e.g. VHF) is advantageous for the in-house radio coverage.

The frequency spectrum requirements of such a system is derived based on a DVB-T television channel in the VHF range (VHF band I 47 – 68 MHz, VHF band II 87.5 – 108 MHz, and VHF band III 174 – 230 MHz). According to [TUM] channels with a bandwidth of 7 MHz are used for television broadcast in the VHF band. Dependent on the settings here a data rate of 12 – 20 Mbit/s per channel can be achieved.

To derive the frequency requirement a conservative assumption of 12 MBit/s per channel is made. Concerning duplex operation one channel is necessary for each of the directions. Thus, a data rate of **12 Mbit/s** per **14 MHz** is resulting.

6.3.7 IEEE 802.11p (Car-to-car communication)

IEEE 802.11p is an enhancement of IEEE 802.11 to standardize the car-to-car communication. According to [C2C CC] the ETSI was requested concerning 7 x 10 MHz channels for different applications in the frequency range of 5.855 - 5.925 GHz. The following data rates are to be supported: 3 / 4.5 / 6 / 9 / 12 / 18 / 24 / 27 Mbit/s. The default data rate is 6 Mbit/s.

Thus, **6 Mbit/s** per **10 MHz** are calculated to derive the frequency spectrum requirements.

6.3.8 Directional radio links

Directional radio links for PPDR agencies can be realized at different frequencies (see the according radio directive of the German Federal Ministry of Interior), e.g.:

- Directional radio links of the PPDR agencies:
  - 1690 – 1693 MHz
  - 1782 – 1785 MHz

- Transmission of picture, audio, and data signals with point-to-point radio links (14250 – 14500 MHz)
  - Channel pattern 1: 18 channels, spacing 14 MHz
  - Channel pattern 2: 17 channels, spacing 14 MHz

- Pattern 1 and pattern 2 are overlapping

To derivate the frequency requirement the channel spacing of the 14 GHz band is used. As a consequence, **14 MHz per directional radio channel** are resulting.

6.3.9 Summary

In the following the results for the derivaton of the frequency spectrum required for the different technologies have been summarized:

:

technology		frequency spectrum required per Mbit/s
Ad hoc network in the 5GHz band	802.11a	20 MHz channel per 9 Mbit/s
	802.11n	40 MHz channel per 48 Mbit/s
WLAN technology	802.11g	22 MHz channel per 28 Mbit/s
	802.11a	20 MHz channel per 28 Mbit/s
LTE (Release 8)	downlink	20MHz per 160 Mbit/s
	uplink	20 MHz per 108 Mbit/s
LTE Advanced (Release 10)	downlink	80MHz per 320Mbit/s
	uplink	40MHz per 432Mbit/s
satellite		0,8 MHz per 1 Mbit/s
indoor radio		14 MHz per 12 Mbit/s
IEEE 802.11p		10 MHz per 6 Mbit/s
directional radio		14 MHz per channel

Table 6-12: frequency spectrum required for the different technologies

6.4 Derivation of the required frequency spectrum for the PPDR scenarios

Based on the frequency spectrum required per communication technology per Mbit/s (see Table 6-12) in the following the derivation of the overall frequency spectrum required per technology to fulfil the theoretically maximal overall bandwidth requirements of the PPDR agencies is described in detail. The derivation of the overall frequency spectrum required to fulfil the overall bandwidth requirements under consideration of operational priorisations (“mission critical”, “realtime”, “no redundancy”) has been done next. All results are listed in Table 6-13.

6.4.1 Ad hoc networks:

Usage of IEEE 802.11a: The theoretically maximal overall bandwidth requirements are 312 Mbit/s. The frequency spectrum required for 9 Mbit/s is a 20 MHz channel. Therefore in total 35 channels with 20 MHz each are required, resulting in an overall frequency spectrum requirement of **700 MHz**.

Usage of IEEE 802.11n: In case of using IEEE 802.11n the frequency spectrum requirements is 40 MHz for 48 Mbit/s, which results in a total frequency spectrum requirement of 7 channels with 40 MHz each, that is, **280 MHz**.

6.4.2 WLAN technology:

The theoretically maximal overall bandwidth requirements are 35 Mbit/s. The frequency spectrum required for 28 Mbit/s is a 20 MHz channel in the 5 GHz band respectively a 22 MHz channel in the 2,4 GHz band. Therefore in total 2 channels are required, resulting in an overall frequency spectrum requirement of **40 MHz** respectively **44 MHz**.

6.4.3 LTE (Release 8):

Downlink: The theoretically maximal overall bandwidth requirements are 613 Mbit/s. The frequency spectrum required for 160 Mbit/s are 20 MHz. Therefore in total 4 times 20 MHz are required, resulting in an overall frequency spectrum requirement of **80 MHz**.

Uplink: The theoretically maximal overall bandwidth requirements are 651 Mbit/s. The frequency spectrum required for 108 Mbit/s are 20 MHz. Therefore in total about 6 times 20 MHz are required, resulting in an overall frequency spectrum requirement of **120 MHz**.

In total this results in an overall frequency spectrum requirement of **200 MHz** for up- and downlink.

6.4.4 LTE Advanced (Release 10):

Downlink: The theoretically maximal overall bandwidth requirements are 613 Mbit/s. The frequency spectrum required for 320 Mbit/s are 80 MHz. Therefore in total 2 times 80 MHz are required, resulting in an overall frequency spectrum requirement of **160 MHz**.

Uplink: The theoretically maximal overall bandwidth requirements are 651 Mbit/s. The frequency spectrum required for 432 Mbit/s are 40 MHz. Therefore in total about 2 times 40 MHz channels are required, resulting in an overall frequency spectrum requirement of **80 MHz**.

In total this results in an overall frequency spectrum requirement of **240 MHz** for up- and downlink, which wouldn’t reflect a bandwidth saving compared to LTE (Release 8). Therefore in the following only the values for LTE (Release 8) will be considered.

6.4.5 Satellite technology:

The theoretically maximal overall bandwidth requirements are 360,5 Mbit/s duplex. The frequency spectrum required for 1 Mbit/s are 0,8 MHz. This results in total in an overall frequency spectrum requirement of **288,4 MHz**.

6.4.6 Indoor radio:

The theoretically maximal overall bandwidth requirements are 9,6 Mbit/s. The frequency spectrum required for 12 Mbit/s are 14 MHz (2 channels in duplex operation). This results in total in an overall frequency spectrum requirement of **14 MHz**.

6.4.7 IEEE 802.11p:

The theoretically maximal overall bandwidth requirements are 0,1 Mbit/s. With a frequency spectrum of 10 MHz required for 6 Mbit/s, in total one **10 MHz** channel is sufficient to fulfil the theoretically maximal overall bandwidth requirements.

6.4.8 Directional radio (without specification of the respective frequency band):

The theoretically maximal overall bandwidth requirements are 40 channels. Per channel 14 MHz are required, resulting in total in an overall frequency spectrum requirement of **560 MHz**.

6.4.9 Directional radio within the 14GHz band:

The theoretically maximal overall bandwidth requirements are 20 channels. Per channel 14 MHz are required, resulting in total in an overall frequency spectrum requirement of **280 MHz**.

6.4.10 Overall frequency spectrum requirements considering operational priorisations:

Beside the overall frequency spectrum requirements for fulfilling the theoretically maximal overall bandwidth requirements in the following table also the overall frequency spectrum requirements considering operational priorisations are listed. All bandwidth requirements used are the ones listed in Table 6-11.

technology	maximal	mission critical	realzeit	no redundancy
ad hoc 5 GHz (in MHz) 802.11a (802.11n)	700 (280)	420 (160)	420 (160)	400 (160)
WLAN 802.11 (in MHz)	40/44	20/22	20/22	0
LTE downlink (in MHz)	80	40	20	20
LTE uplink (in MHz)	120	60	40	40
satellite (in MHz)	288	208	208	0,4
indoor radio (in MHz)	14	14	14	14
802.11p (in MHz)	10	0	0	0
directional radio (in MHz)	560	546	546	546
direct. radio 14 GHz (in MHz)	280	280	280	280

Table 6-13: frequency spectrum required considering operational priorisations

6.5 Required special frequencies

Some PPDR agencies have required explicitely specific frequencies for some scenarios. These requirements are listed in Table 6-14.

scenario	frequency	channels	category	note
2.1, 2.2	*4m, 2m, 70cm band*	*19*	*A, B, C*	*analogue radio*
2.3	*not specified*	*1*	*A, B, C*	*communic. with drones above 15km, 1 Mbit/s*
11.2	*DVB-T 2.3 GHz*	*15*	*A, B, C*	*video transmission*
14.1	*868 MHz*	*1*	*A, B, C*	*control systems for marksman*
14.2	*446 MHz*	*1*	*A, B, C*	*remote triggering of blasting compositions*
7.7	*MHz-band, radio bearing*	*1*	*A, B*	*radio bearing: 15km, pervasion of buildings 50 kbit/s per connection*
7.9	*MHz-band, underwater comm.*	*10*	*A, B, C*	*voice communication between divers and their commanders*
5.4	*different frequencies*	*1*	*A, B, C*	*narrowband communication (1kbit/s)*
10.2	*maritime comm..*	*1*	*A, B, C*	*international maritime communication*
10.4	*PPDR frequencies: 35cm, 70cm, 2m, 4m, 2,4GHz, 5GHz, 14 GHz*	*?*	*A, B, C*	fallback for reconnaissance (audio and video)

Table 6-14: Required specific frequencies

7 Main recommendations for action

From the statistical analysis as well as from the determination of the bandwidth and frequency spectrum requirements numerous findings result. From those the main recommendations for further action can be derived, which are outlined shortly in the following.

The analysis clearly show, that a single communication technology cannot fulfil the whole range of user requirements, rather a combination of different communication technologies is required. These can be IEEE 802.11p, WLAN, technologies for a flexible ad hoc communication at the operation site in the 5 GHz band without dependency on infrastructures, technologies for the temporary inhouse radio coverage of buildings in the lower and middle MHz band, technologies from emerging cellular networks like LTE, satellite links and further specific technologies.

For 802.11p, WLAN and satellite it doesn't make sense to request own frequency spectrum for PPDR usage, as those established technologies have already assigned their own frequency spectrum. The consequence of reserving a different spectrum would be an incompatibility to the established technology.

For special technologies there is typically also no action required concerning further frequency planning, as for each of these technologies usually a frequency assignment has been done already.

Important would be a frequency spectrum reservation of 60 MHz (20 MHz downlink, 40 MHz uplink) for the usage of LTEm type technology by PPDR agencies. This would allow the deployment of an established and broadly used emerging cellular technologies by the PPDR agencies with own and exclusive frequencies. This exclusive PPDR usage would be the basis for fulfilling the required high availability of the network, and is also necessary for deploying the communication scenarios, which are mission critical.

Additionally frequencies for the deployment of technologies for the ad hoc communication at the operation site are required in order to achieve for different applications a complete independency from any infrastructure networks. This would require a frequency spectrum reservation of 160 MHz for the usage by PPDR agencies. Here it would be beneficial to make use of the frequency band from 5,15 GHz to 5,25 GHz, which is already today assigned for the performance of Broadband Disaster Relief operations by the European PPDR agencies. Using this already assigned 100 MHz it would be sufficient to reserve additional 60 MHz. Ideally these 60 MHz should be immediately above 5,25 MHz in order to allow for a usage of existing communication technologies based on IEEE 802.11a.

Finally a reservation of frequency spectrum for the temporary inhouse coverage of buildings is required. Here a frequency band should be chosen, which ensures an efficient pervasion of buildings. Todays telemetry applications in the 800 MHz band fulfil this only partly. Therefore the focus should be to reserve a frequency spectrum below 800 MHz. A frequency spectrum of 14 MHz in total should be sufficient.

8 References

[802.11n] http://de.wikipedia.org/wiki/IEEE_802.11n

[NC] http://www.networkcomputing.de/kommunikation/mobile-wireless/artikel-4928.html

[3GPP] www.3gpp.org/LTE

[3GPP IMT] Takehiro Nakamura (3GPP TSG-RAN Chairman), “Proposal for Candidate Radio Interface Technologies for IMT-Advnaced based on LTE Release 10 and Beyond (LTE Advanced)”, Presentation for 3GPP IMT-Advanced Evaluation Workshop, Beijing, China, December 2009

[Qualcomm] Qualcomm: „LTE Release 8 and beyond“, April 2009

[Ericsson] Ericsson: „Hintergrundinformation: HSPA und LTE“, Juni 2008

[NSN] http://www.nokiasiemensnetworks.com/press/press-releases/researchers-at-nsn-double-the-capacity-in-uplink-using-virtual-mimo

[NTT] http://www.nttdocomo.com/pr/2008/001390.html

[T-Mobil] http://www.huawei.com/de/catalog.do?id=611

[TUM] Book „Modulationsverfahren“, Institute for Communications Engineering, Technical University Munich

[C2C CC] Car-to-Car Communication Consortium, „CAR 2 CAR Communication Consortium Manifesto“

9 Annex

9.1 Annex A: Overall bandwidth requirements without consideration of operation specific priorisation

9.1.1 Normal operation (category A)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
1.1			4	4						
2.4							1			
3.1, 4.3, 8.2, 18.2, 19.2, 16.3	15								2	
3.2			0,03	0,03						
3.3										0,1
3.4			0,1	2						
3.5			0,1	0,01						
3.7			3	3						
3.6, 4.4, 8.1, 16.2			10	6						
4.2			0,001	0,001						
4.1			8	8						
8.3							1			
18.1, 19.1	22									
18.3		4					1			
18.4	11	11					1			
19.3	1									
9.1	0,512		16	16						
9.2					100	100				
16.1	4									
17.1							1			
17.2	4								4	
17.3					0,5	0,5				
20.1			4	0,25						
20.2	2		0,25	2						
11.1, 13.1							10	10		
11.2							3			
11.3, 12.1, 13.5			40	40						
11.4, 12.3	12,5									
11.5							5	5		
12.2	50									
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			4	4						
13.7			5,12	5,12						
13.8	4									
14.3	8		24	24						
14.4			5,12	5,12						
14.5	0,01									
7.1			6	6	260	260				
7.3			4	4						
7.4			40	40						
7.5			30	30						
7.6			20	20						
7.8			0,15	0,15						
7.10		20								
6.1	15		2	15					1	
5.1			20	20						
5.2	48		48	48						
5.3			0,32	0,32						
10.1							2			
10.2			33,2	33,2						
10.3			26,4	26,4						
10.4	41,6								2,6	
total	**238,622**	**35**	**354,851**	**387,601**	**360,5**	**360,5**	**25**	**15**	**9,6**	**0,1**

Table 9-1: Overall bandwidth requirements without consideration of operation specific priorisation, in category A

9.1.2 Demonstrations and mass events (category B)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
2.4							1			
3.1, 4.3, 18.2	15								1	
3.2			0,03	0,03						
3.3										0,1
3.4			0,5	10						
3.5			0,1	0,01						
3.6, 4.4, 16.2			50	12,5						
4.2			0,3	0,3						
4.1			8	8						
18.1	22									
18.4	11	11					1			
9.1	40		4	4						
16.1	10									
17.1							1			
17.2			8	8						
17.3					0,5	0,5				
11.1, 13.1							10	10		
11.2							15			
11.3, 12.1, 13.5			80	80						
11.4, 12.3	12,5									
11.5							10	10		
12.2	50									
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			80	80						
13.7			5,12	5,12						
13.8	4									
14.3	8		8	8						
14.4			25,6	25,6						
14.5	0,01									
7.1			6	6	260	260				
7.3			4	4						
7.4			40	40						
7.5			30	30						
7.6			100	100						
7.8			0,15	0,15						
7.10		20								
6.1	50		6	50					1	
5.1			20	20						
5.2	48		48	48						
5.3			0,32	0,32						
10.1							2			
10.2			33,2	33,2						
10.3			52,8	52,8						
10.4	41,6								2,6	
total	**312,11**	**31**	**611,18**	**651,03**	**260,5**	**260,5**	**40**	**20**	**4,6**	**0,1**

Table 9-2: Overall bandwidth requirements without consideration of operation specific priorisation, in category B

9.1.3 Natural and major disasters (category C)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
2.4							1			
3.1, 4.3, 8.2, 18.2, 19.2, 16.3	15								2	
3.2			0,03	0,3						
3.3										0,1
3.4			0,5	10						
3.5			0,2	0,02						
3.7			3	3						
3.8							1			
3.6, 4.4, 8.1, 16.2			50	12,5						
4.2			0,3	0,3						
4.1			8	8						
8.3							1			
18.1, 19.1	22									
18.4	11	11					1			
19.3	1									
9.1	40		4	4						
16.1	8									
17.1							1			
17.2			8	8						
17.3					0,5	0,5				
11.1, 13.1							10	10		
11.2										
11.3, 12.1, 13.5			80	80						
11.4, 12.3	12,5									
11.5							10	10		
12.2	50									
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			80	80						
13.7			5,12	5,12						
13.8	4									
14.3	8		8	8						
14.4			25,6	25,6						
14.5	0,01									
7.1			6	6	260	260				
7.3			4	4						
7.4			40	40						
7.5			30	30						
7.6			100	100						
7.8			0,15	0,15						
7.10		20								
6.1	15		2	15					1	
6.2			2	2						
5.1			20	20						
5.2	48		48	48						
5.3			0,9	0,9						
10.1							2			
10.2			33,2	33,2						
10.3			52,8	52,8						
10.4	41,6								2,6	
total	**276,11**	**31**	**612,86**	**621,89**	**260,5**	**260,5**	**27**	**20**	**5,6**	**0,1**

Table 9-3: Overall bandwidth requirements without consideration of operation specific priorisation, in category C

9.2 Annex B: Overall bandwidth requirements of the “mission critical” communication scenarios

All scenarios, which havn’t been considered „mission critical“, have been marked in red in the following tables. Their bandwidth requirements havn’t been considered for determination oft he overall bandwidth requirements.

9.2.1 Normal operation (category A)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
1.1										
2.4										
3.1, 4.3, 8.2, 18.2, 19.2, 16.3	10								2	
3.2			0,03	0,03						
3.3										
3.4										
3.5										
3.7										
3.6, 4.4, 8.1, 16.2			2	2						
4.2										
4.1			8	8						
8.3										
18.1, 19.1	4									
18.3		4					1			
18.4	11	11					1			
19.3										
9.1	0,512		16	16						
9.2										
16.1	4									
17.1							1			
17.2	2								4	
17.3					0,5	0,5				
20.1										
20.2										
11.1, 13.1							10	10		
11.2										
11.3, 12.1, 13.5			20	20						
11.4, 12.3	10									
11.5										
12.2										
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			4	4						
13.7										
13.8	4									
14.3	8		24	24						
14.4										
14.5	0,01									
7.1			6	6	260	260				
7.3			4	4						
7.4			40	40						
7.5										
7.6										
7.8										
7.10										
6.1	15		2	15					1	
5.1										
5.2										
5.3										
10.1							2			
10.2			33,2	33,2						
10.3			26,4	26,4						
10.4	41,6								2,6	
total	**110,122**	**15**	**186,69**	**223,63**	**260,5**	**260,5**	**15**	**10**	**9,6**	**0**

Table 9-4: Overall bandwidth requirements of the "mission critical" communication scenarios, in category A

9.2.2 Demonstrations and mass events (category B)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
2.4										
3.1, 4.3, 18.2	10								1	
3.2			0,03	0,03						
3.3										
3.4										
3.5										
3.6, 4.4, 16.2			2	2						
4.2										
4.1			8	8						
18.1	4									
18.4	11	11					1			
9.1	40		4	4						
16.1	10									
17.1							1			
17.2			2	2						
17.3					0,5	0,5				
11.1, 13.1							10	10		
11.2							15			
11.3, 12.1, 13.5			20	20						
11.4, 12.3	10									
11.5							10	10		
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			80	80						
13.7										
13.8	4									
14.3	8		8	8						
14.4										
14.5	0,01									
7.1			6	6	260	260				
7.3			4	4						
7.4			40	40						
7.5										
7.6										
7.8										
7.10										
6.1	50		6	50					1	
5.1										
5.2										
5.3										
10.1							2			
10.2			33,2	33,2						
10.3			52,8	52,8						
10.4	41,6								2,6	
total	**188,61**	**11**	**267,09**	**335,03**	**260,5**	**260,5**	**39**	**20**	**4,6**	**0**

Table 9-5: Overall bandwidth requirements of the "mission critical" communication scenarios, in category B

9.2.3 Natural and major disasters (category C)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
2.4										
3.1, 4.3, 8.2, 18.2, 19.2, 16.3	10								2	
3.2			0,03	0,3						
3.3										
3.4										
3.5										
3.7										
3.8							1			
3.6, 4.4, 8.1, 16.2			2	2						
4.2										
4.1			8	8						
8.3										
18.1, 19.1	4									
18.4	11	11					1			
19.3										
9.1	40		4	4						
16.1	8									
17.1							1			
17.2			2	2						
17.3					0,5	0,5				
11.1, 13.1							10	10		
11.2										
11.3, 12.1, 13.5			20	20						
11.4, 12.3	10									
11.5							10	10		
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			80	80						
13.7										
13.8	4									
14.3	8		8	8						
14.4										
14.5	0,01									
7.1			6	6	260	260				
7.3			4	4						
7.4			40	40						
7.5										
7.6										
7.8										
7.10										
6.1	15		2	15					1	
6.2										
5.1										
5.2										
5.3										
10.1							2			
10.2			33,2	33,2						
10.3			52,8	52,8						
10.4	41,6								2,6	
total	**151,61**	**11**	**263,09**	**300,3**	**260,5**	**260,5**	**25**	**20**	**5,6**	**0**

Table 9-6: Overall bandwidth requirements of the "mission critical" communication scenarios, in category C

9.3 Annex C: Overall bandwidth requirements of the “mission critical” scenarios, which have also real-time requirements

All scenarios, which havn’t been considered „mission critical“, have been marked in red in the following tables, all scenarios, which have realtime requirements have been marked in blue. The bandwidth requirements of both of them havn’t been considered for determination oft he overall bandwidth requirements.

9.3.1 Normal operation (category A)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
1.1										
2.4										
3.1, 4.3, 8.2, 18.2, 19.2, 16.3	10								2	
3.2			0,03	0,03						
3.3										
3.4										
3.5										
3.7										
3.6, 4.4, 8.1, 16.2			2	2						
4.2										
4.1			8	8						
8.3										
18.1, 19.1	4									
18.3		4					1			
18.4	11	11					1			
19.3										
9.1	0,512		16	16						
9.2										
16.1	4									
17.1							1			
17.2	2								4	
17.3					0,5	0,5				
20.1										
20.2										
11.1, 13.1							10	10		
11.2										
11.3, 12.1, 13.5			20	20						
11.4, 12.3	10									
11.5										
12.2										
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			4	4						
13.7										
13.8	4									
14.3	8		24	24						
14.4										
14.5	0,01									
7.1			6	6	260	260				
7.3			4	4						
7.4										
7.5										
7.6										
7.8										
7.10										
6.1	15		2	15					1	
5.1										
5.2										
5.3										
10.1							2			
10.2			3,2	3,2						
10.3			26,4	26,4						
10.4	41,6								2,6	
total	**110,122**	**15**	**116,69**	**153,63**	**260,5**	**260,5**	**15**	**10**	**9,6**	**0**

Table 9-7: Overall bandwidth requirements of the "mission critical" scenarios, which have also real-time requirements, in category A

9.3.2 Demonstrations and mass events (category B)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
2.4										
3.1, 4.3, 18.2	10								1	
3.2			0,03	0,03						
3.3										
3.4										
3.5										
3.6, 4.4, 16.2			2	2						
4.2										
4.1			8	8						
18.1	4									
18.4	11	11					1			
9.1	40		4	4						
16.1	10									
17.1							1			
17.2			2	2						
17.3					0,5	0,5				
11.1, 13.1							10	10		
11.2							15			
11.3, 12.1, 13.5			20	20						
11.4, 12.3	10									
11.5							10	10		
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			80	80						
13.7										
13.8	4									
14.3	8		8	8						
14.4										
14.5	0,01									
7.1			6	6	260	260				
7.3			4	4						
7.4										
7.5										
7.6										
7.8										
7.10										
6.1	50		6	50					1	
5.1										
5.2										
5.3										
10.1							2			
10.2			3,2	3,2						
10.3			52,8	52,8						
10.4	41,6								2,6	
total	**188,61**	**11**	**197,09**	**265,03**	**260,5**	**260,5**	**39**	**20**	**4,6**	**0**

Table 9-8: Overall bandwidth requirements of the "mission critical" scenarios, which have also real-time requirements, in category B

9.3.3 Natural and major disasters (category C)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
2.4										
3.1, 4.3, 8.2, 18.2, 19.2, 16.3	10								2	
3.2			0,03	0,3						
3.3										
3.4										
3.5										
3.7										
3.8							1			
3.6, 4.4, 8.1, 16.2			2	2						
4.2										
4.1			8	8						
8.3										
18.1, 19.1	4									
18.4	11	11					1			
19.3										
9.1	40		4	4						
16.1	8									
17.1							1			
17.2			2	2						
17.3					0,5	0,5				
11.1, 13.1							10	10		
11.2										
11.3, 12.1, 13.5			20	20						
11.4, 12.3	10									
11.5							10	10		
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			80	80						
13.7										
13.8	4									
14.3	8		8	8						
14.4										
14.5	0,01									
7.1			6	6	260	260				
7.3			4	4						
7.4										
7.5										
7.6										
7.8										
7.10										
6.1	15		2	15					1	
6.2										
5.1										
5.2										
5.3										
10.1							2			
10.2			3,2	3,2						
10.3			52,8	52,8						
10.4	41,6								2,6	
total	**151,61**	**11**	**193,09**	**230,3**	**260,5**	**260,5**	**25**	**20**	**5,6**	**0**

Table 9-9: Overall bandwidth requirements of the "mission critical" scenarios, which have also real-time requirements, in category C

9.4 Annex D: Overall bandwidth requirements of the “mission critical” scenarios, which have realtime requirements and are not used for redundancy reasons

All scenarios, which havn’t been considered „mission critical“, have been marked in red in the following tables, all scenarios, which have realtime requirements have been marked in blue, scenarios, which are used for redundancy reasons only, have been marked in green. The bandwidth requirements all of them havn’t been considered for determination oft he overall bandwidth requirements.

9.4.1 Normal operation (category A)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
1.1										
2.4										
3.1, 4.3, 8.2, 18.2, 19.2, 16.3	10								2	
3.2			0,03	0,03						
3.3										
3.4										
3.5										
3.7										
3.6, 4.4, 8.1, 16.2			2	2						
4.2										
4.1			8	8						
8.3										
18.1, 19.1	4									
18.3							1			
18.4							1			
19.3										
9.1	0,512		16	16						
9.2										
16.1	4									
17.1							1			
17.2	2								4	
17.3					0,5	0,5				
20.1										
20.2										
11.1, 13.1							10	10		
11.2										
11.3, 12.1, 13.5			20	20						
11.4, 12.3	10									
11.5										
12.2										
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			4	4						
13.7										
13.8	4									
14.3	8		24	24						
14.4										
14.5	0,01									
7.1										
7.3										
7.4										
7.5										
7.6										
7.8										
7.10										
6.1	15		2	15					1	
5.1										
5.2										
5.3										
10.1							2			
10.2			3,2	3,2						
10.3			26,4	26,4						
10.4	41,6								2,6	
total	**99,122**	**0**	**106,69**	**143,63**	**0,5**	**0,5**	**15**	**10**	**9,6**	**0**

Table 9-10: Overall bandwidth requirements of the "mission critical" scenarios, which have realtime requirements and are not used for redundancy reasons, in category A

9.4.2 Demonstrations and mass events (category B)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
2.4										
3.1, 4.3, 18.2	10								1	
3.2			0,03	0,03						
3.3										
3.4										
3.5										
3.6, 4.4, 16.2			2	2						
4.2										
4.1			8	8						
18.1	4									
18.4							1			
9.1	40		4	4						
16.1	10									
17.1							1			
17.2			2	2						
17.3					0,5	0,5				
11.1, 13.1							10	10		
11.2							15			
11.3, 12.1, 13.5			20	20						
11.4, 12.3	10									
11.5							10	10		
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			80	80						
13.7										
13.8	4									
14.3	8		8	8						
14.4										
14.5	0,01									
7.1										
7.3										
7.4										
7.5										
7.6										
7.8										
7.10										
6.1	50		6	50					1	
5.1										
5.2										
5.3										
10.1							2			
10.2			3,2	3,2						
10.3			52,8	52,8						
10.4	41,6								2,6	
total	**177,61**	**0**	**187,09**	**255,03**	**0,5**	**0,5**	**39**	**20**	**4,6**	**0**

Table 9-11: Overall bandwidth requirements of the "mission critical" scenarios, which have realtime requirements and are not used for redundancy reasons, in category B

9.4.3 Natural and major disasters (category C)

user.scenario	ad hoc GHz	WLAN	LTE (per cell in Mbit/s) down	LTE (per cell in Mbit/s) up	satellite down	satellite up	radio link (channel)	radio link video 14GHz (channel)	radio system for inhouse operation	802.11p (Mbit/s)
2.4										
3.1, 4.3, 8.2, 18.2, 19.2, 16.3	10								2	
3.2			0,03	0,3						
3.3										
3.4										
3.5										
3.7										
3.8							1			
3.6, 4.4, 8.1, 16.2			2	2						
4.2										
4.1			8	8						
8.3										
18.1, 19.1	4									
18.4							1			
19.3										
9.1	40		4	4						
16.1	8									
17.1							1			
17.2			2	2						
17.3					0,5	0,5				
11.1, 13.1							10	10		
11.2										
11.3, 12.1, 13.5			20	20						
11.4, 12.3	10									
11.5							10	10		
13.2			0,01	4						
13.3			0,05	20						
13.4			1	1						
13.6			80	80						
13.7										
13.8	4									
14.3	8		8	8						
14.4										
14.5	0,01									
7.1										
7.3										
7.4										
7.5										
7.6										
7.8										
7.10										
6.1	15		2	15					1	
6.2										
5.1										
5.2										
5.3										
10.1							2			
10.2			3,2	3,2						
10.3			52,8	52,8						
10.4	41,6								2,6	
total	**140,61**	**0**	**183,09**	**220,3**	**0,5**	**0,5**	**25**	**20**	**5,6**	**0**

Table 9-12: Overall bandwidth requirements of the "mission critical" scenarios, which have realtime requirements and are not used for redundancy reasons, in category C