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Public Protection and Disaster Relief Communications

1.1 Background and Terminology

The public protection and disaster relief (PPDR) sector brings essential value to society by creating a stable and secure environment to maintain law and order and to protect the life and values of citizens. PPDR services such as law enforcement, firefighting, emergency medical services (EMS) and disaster recovery services are pillars of our society organization. The protection ensured by PPDR services covers people, property, the environment and other relevant values for the society. It addresses a large number of threats both natural and man-made. The PPDR sector is for most nations intimately connected to the public sector of society, either directly as part of the governmental structure or as a function which is outsourced under strict rules and intensively monitored by government's contracting ministry or department. Regulatory, organizational, operational and technical elements underpinning an effective PPDR preparedness can vary substantially from country to country, even between regions or municipalities in countries where local preparedness might be under the auspices of regional or local public authorities.

One important task of PPDR services is to deal with emergency and surveillance situations on land, sea and air. The most important part of this work is done in the field, so all the tools must match the needs accordingly. Radiocommunications are extremely important to PPDR organizations to the extent that PPDR communications are highly dependent upon it. At times, radiocommunication is the only form of communications available.

There are terminology differences between administrations and regions in the scope and specific meaning of PPDR and related radiocommunication services. PPDR is defined in ITU Radiocommunication (ITU-R) Resolution 646 in World Radio Conference 2003 (WRC-03)

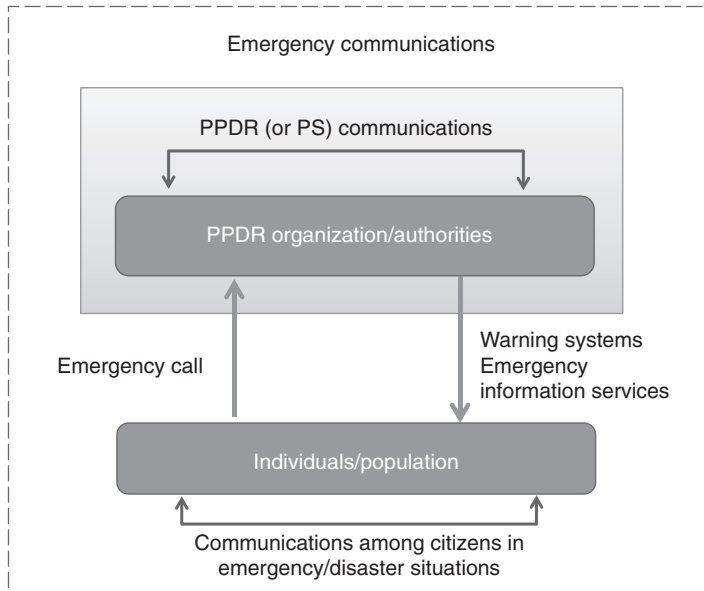


Figure 1.1 Scope of PPDR and emergency communications.

through a combination of the terms ‘public protection (PP) radiocommunication’ and ‘disaster relief (DR) radiocommunication’ [1]:

- **PP radiocommunication.** Radiocommunications used by responsible agencies and organizations dealing with maintenance of law and order, protection of life and property and emergency situations
- **DR radiocommunication.** Radiocommunications used by agencies and organizations dealing with a serious disruption of the functioning of society, posing a significant, widespread threat to human life, health, property or the environment, whether caused by accident, nature or human activity

A term also commonly used to refer to PPDR communications is public safety (PS) communications. These terms are often used interchangeably [2]. Another term related to PPDR communications is emergency communications. Broadly defined, emergency communications involves not only communications within and between PPDR agencies and public authorities involved in the management of an emergency case but also communications involving citizens. As illustrated in Figure 1.1, the generally agreed categories to be considered in the provision of emergency communications are [3]:

- **Communication between authorities/organizations.** Refers to communications within and among authorities/organizations. This is the category that fits with the scope of PPDR communications.
- **Communication from authorities/organizations to citizens.** Refers to communications from authorities/organizations with individuals, groups or the general public. Warning and information systems to alert the population are part of this category.

- **Communication of citizens with authorities/organizations.** Emergency call services (e.g. calls to emergency numbers such as 112 or 911 through public telephone networks) are part of this category.
- **Communication among citizens.** In case of a disaster, individuals may have a strong demand to communicate among themselves in order to ascertain/learn the state of relatives, property, etc., as well as coordinate actions of mutual interest. Particularly, new social media communications technologies can potentially enable citizens to more quickly share information, assist response and recovery in emergencies and mobilize for action in political crises.

In this context, it is also common to refer to PPDR organizations as emergency services or emergency response providers. In particular, an emergency service can be defined as an agency or service that provides immediate and rapid assistance in situations where there is a direct risk to life or limb, individual or public health or safety, private or public property, or the environment but not necessarily limited to these situations [4].

The focus of this book is on communications within and between PPDR organizations and authorities. In this regard, the terms PPDR, PS and emergency communications are used interchangeably within the book to refer to this type of communications.

1.2 PPDR Functions and Organizations

PPDR organizations or agencies are the ones responsible for the prevention and protection from events that could endanger the safety of the general public. The main functions and services provided by PPDR organizations are [5, 6]:

- **Law enforcement.** Law enforcement is the function to prevent, investigate, apprehend or detain any individual, which is suspected or convicted of offences against the criminal law. Law enforcement is a function usually performed by police organizations.
- **EMS.** The function of medical services is to provide critical invasive and supportive care of sick and injured citizens and the ability to transfer the people in a safe and controlled environment. Components of the EMS system include the following: medical first responders (people and agencies that provide non-transporting first aid care before an ambulance arrives on scene), ambulance services (basic and advanced life support), specialty transport services (helicopter, boat, snowmobile, etc.), hospitals (emergency, intensive, cardiac, neonatal care units, etc.) and specialty centres (trauma, burn, cardiac, drug units, etc.). The function of EMS includes also the function of ‘disaster medicine’, which is the provision of triage, primary aid, transportation and secondary care in major incidents. Doctors, paramedics, medical technicians, nurses or volunteers can supply these services.
- **Firefighting.** This is the function of putting out hazardous fires that threaten civilian populations and property. Hazardous fires can appear in urban areas (houses or buildings) or rural areas (forest fires). Professional and volunteer fire protection agencies supply this service.
- **Protection of the environment.** This is the function to protect the natural environment of a nation or a regional area, including its ecosystems composed by animals and plants. This function is limited to the everyday operation of protecting the environment like monitoring of the water, air and land. Forest guards, firefighters, volunteer organizations or public organizations are usually responsible for this activity.

- **Search and rescue.** This function has the objective to locate, access, stabilize and transport lost or missing persons to a place of safety. Search and rescue is one of the activities performed by different PS organizations such as firefighters or EMS.
- **Border security.** Control of the border of a nation or a regional area from intruders or other threats, which could endanger the safety and economic well-being of citizens. Covers areas such as verification of illegal immigration, verification of the introduction of illegal substances and verification of introduction of goods in offence of customs laws. Border security is usually performed by police organizations or specialized border security guard. Coastal guard is a special case of border security.
- **Emergency management.** Emergency management, also referred to as civil protection, is the organization and management of resources and responsibilities for dealing with all aspects of major emergencies/disasters, in particular prevention, preparedness, response and rehabilitation. Emergency management provides central command and control of PPDR agencies during emergencies. Emergency management involves plans, structures and arrangements established to engage the normal endeavours of government, voluntary and private agencies in a comprehensive and coordinated way to respond to the whole spectrum of major emergency needs. Emergency management includes also the recovery of the essential flows related to food, health, transportation, building material, electrical energy supply, telecommunications and daily stuff, situation awareness and communication.

The distribution of the above functions and services among PPDR organizations is not homogeneous across countries and regions. In Europe, similar organizations may not perform exactly the same functions in different countries due to the non-homogeneous historical development of PPDR services in each nation. Also, the organization and standard operating procedures can differ significantly among PPDR organizations that could span from volunteer organizations, which have received limited training, to specialist paramilitary organizations (e.g. explosives, hazardous materials specialists). Common types of PPDR organizations in Europe are described in the following list, identifying which is the main function or functions provided by each:

- **Police.** The main objective of the police is law enforcement creating a safer environment for its citizen. Functions: law enforcement.
- **Fire services.** With variations from region to region and country to country, the primary areas of responsibility of the fire services include structure firefighting and fire safety, wild land firefighting, life-saving through search and rescue, rendering humanitarian services, management of hazardous materials and protecting the environment, salvage and damage control, safety management within an inner cordon and mass decontamination. Functions: law enforcement, protection of the environment and search and rescue.
- **Border guard (land).** Border guard comprises national security agencies which perform border control at national or regional borders. Their duties are usually criminal interdiction, control of illegal immigration and illegal trafficking. Functions: law enforcement and border security.
- **Coast guard.** Coast guard services may include, but not be limited to, search and rescue (at sea and other waterways), protection of coastal waters, criminal interdiction, illegal immigration and disaster and humanitarian assistance in areas of operation. Coast guard functions may vary with administrations, but core functions and requirements are generally

common globally. Functions: law enforcement, protection of the environment, search and rescue and border security.

- **Forest guards.** Type of police specialized in the protection of the forest environment. It supports other agencies in firefighting and law enforcement in rural and mountain environment. Functions: law enforcement, protection of the environment and search and rescue.
- **Hospitals and medical first responders.** These are the central components for the provision of EMS. They usually count on mobile units such as ambulances and other motorized vehicles such as aircraft helicopters and other vehicles. Functions: EMS and search and rescue.
- **Road transport police.** Transport police is a specialized police agency responsible for the law enforcement and protection of transportation ways like railroad, highways and others. Functions: law enforcement.
- **Railway transport police.** Railway transport police is a specialized police agency responsible for the law enforcement and protection of railways. In some cases, it is a private organization dependent on the railway service provider. Functions: law enforcement.
- **Custom guard.** An arm of a state's law enforcement body, responsible for monitoring people and goods entering a country. Given the removal of internal borders in the European Union (EU), customs authorities are particularly focused on crime prevention. Functions: law enforcement.
- **Airport security.** Airport enforcement authority is responsible for protecting airports, passengers and aircrafts from crime. Functions: law enforcement.
- **Port security.** Port enforcement authority is responsible for protecting port and maritime harbour facilities. Functions: law enforcement.
- **Volunteers organizations for civil protection.** Volunteer organizations are civilian with training on a number of areas related to PS and environment protection. They voluntarily enter into an agreement to protect environment and citizens without a commercial or monetary profit. Functions: protection of the environment and search and rescue.

In addition to the above-mentioned types of PPDR organizations, public authorities at different levels (local, regional, national) can also be directly involved in PPDR operations, leading or supporting emergency management functions. Public authorities are responsible for the establishment of a set of preparedness and contingency plans to handle emergency situations. Public authorities can be at the core of the response to most serious emergencies to put in place the emergency plans as well as provide advice and assistance to businesses and voluntary organizations about business continuity management.

Moreover, emergency response may also involve other public or private organizations such as departments of transportation, public works, utility companies (water, gas, electricity) and telecom operators. In the case of telecom operators, the emergency management plans may include a listing of emergency telecommunications facilities that need to be prepared for use in the event of a major emergency/disaster. The telecom operators have to support these plans where special operational modes may be predefined in a policy-based network management scheme and invoked in emergency situations (e.g. invocation or priority access schemes, rerouting calls to specific answering points).

Military forces can also support PPDR operations during major national emergencies where military authorities provide manpower and equipment to supplement PS resources. These incidents are frequently in response to natural forces (e.g. flooding, earthquakes). Military

units can also give pre-planned support in major events (e.g. Olympic Games) as well as specialist response to man-made emergencies (e.g. terrorist attacks) where specialist military skills or equipment are necessary and may form an integral part of the emergency response.

Last but not least, some individuals can also belong to entities and organizations that have a role to play in emergency situations [7]. In particular, professionals and/or volunteers in non-governmental organizations (NGOs) and civic organizations may have a supporting role in handling emergencies. Their efficient involvement will highly depend upon their liaisons with the authorities organizing and steering the overall rescue plan. Providing them with tools to report their field observations or get the optimal information on the status of the crisis, they are involved in, can be crucial.

Also, the owners of the site, vessel, etc., where the emergency occurs, have certain obligations to fulfil. Site staff (or personnel) are supposedly fit to manage the site/plant and may participate in the rescue and clearance, as well as being affected individuals. Importantly, assistance in logistic coordination and utility provisioning may be also provided by providers of gas, electricity, electronic communications services and water supply. The utility owner, usually outside the emergency area, may represent control and control its action from a control centre. Utility staff may be directly working within the emergency area (or nearby) with the manual operations needed. Finally, the role of media (journalists, radio/TV news reporters) is also crucial in spreading information from the emergency scene and from the authorities to other affected individuals. Broadcasting can also be used for recruiting and coordinating new people to volunteer.

In this context, the term ‘first responder’ is commonly used to refer to law enforcement, emergency medical, firefighting and rescue services. In turn, the term ‘emergency responders’ is typically used with a wider scope than first responder, including in this case other entities such as electric, water and gas utilities; transportation; transit; search and rescue; hospitals; the Red Cross; and many others, which can be involved in diverse incident responses.

1.3 Operational Framework and Communications Needs for PPDR

PPDR organizations are required to manage emergencies and major incidents on a daily basis. These incidents may vary widely in terms of scale. The definitions of ‘major incident’, ‘emergency’ and similar terms are general in terminology and encompass significant degrees of latitude in their interpretation. Incidents may take on a greater degree of urgency or seriousness because of particular circumstances. For example, a public disorder incident in a town involving 500 people will be more serious in its potential when there are 5 officers to deal with it than where there are 50. Incidents may involve the interaction of multiple PPDR services (police, firefighters, ambulances, specialist units, etc.). In addition, since incidents do not respect administrative, regional and national or language boundaries, operational scenarios may include a variety of cross-border operational activities. According to Ref. [8], a ‘major incident’ is any emergency that requires the implementation of special arrangements by one or more of the emergency services and will generally include the involvement, either directly or indirectly, of large numbers of people. For example:

- The rescue and transportation of large numbers of casualties
- The large-scale combined resources of the emergency services

- The mobilization and organization of the emergency and support services such as local or regional authorities, to deal with the threats of homelessness, serious injury or death involving a large number of people
- The handling of a large number of enquiries generated from the citizen and the mass media, usually directed at the police

It is a strongly held view that requirements for incidents have a considerable degree of commonality. There will be issues of scalability, spatial and temporal considerations, as well as certain incident-specific demands such as cross-border governance procedures, operations to detect and capture offenders in terrorist or criminal incidents and so on.

Within the emergency services, it is both possible and indeed commonplace to develop contingency plans for known risks and where a significant number of values can be defined: counterterrorism plans for an attack on a VIP's residence, evacuation plans for a hospital and a major fire at a large retail centre, for example. However, there are many major incidents which cannot be so clearly defined or prepared for: the cause, location, scale, impact and medium and long-term implications are indeterminate. For this reason, emergency services and other authorities must necessarily build a considerable degree of flexibility into their thinking and operational practices to attempt to build a set of responses to cover every conceivable eventuality and to avoid that these could rapidly become bureaucratic in the extreme, unwieldy and completely unmanageable.

There is a vast literature describing operational scenarios involving PPDR agencies and personnel with the purpose of establishing guidance and best practices as well as deriving organizational, functional and technological (including communications) requirements and standards (e.g. [1, 5, 6, 9–12]). Based on these references, the following subsections provide a comprehensive vision of operational aspects concerning PPDR communications that includes a categorization of PPDR operational scenarios, a description of a generic operational framework, the identification of main components and communications' reference points and the identification of current and expected communications services that are central to PPDR operations.

1.3.1 Operational Scenarios

From the perspective of the use of radiocommunications means in PPDR operations, three distinct radio operating environments are usually defined that impose different requirements on the use of PPDR applications and their importance:

- **Day-to-day operations.** Day-to-day operations encompass the routine operations that PPDR agencies conduct within their jurisdiction. Typically, these operations are within national borders.
- **Large emergency and/or public events.** Large emergencies and/or public events are those that PP and potentially DR agencies respond to in a particular area of their jurisdiction. However, they are still required to perform their routine operations elsewhere within their jurisdiction. The size and nature of the event may require additional PPDR resources from adjacent jurisdictions, cross-border agencies or international organizations. In most cases, there are either plans in place, or there is some time to plan and coordinate the requirements.

A large fire encompassing three to four blocks in a large city or a large forest fire are examples of a large emergency under this scenario. Likewise, a large public event (national or international) could include the G8 Summit, the Olympics, etc.

- **Disasters.** Disasters can be those caused by either natural or human activity. For example, natural disasters include an earthquake, a major tropical storm, a major ice storm, floods, etc. Examples of disasters caused by human activity include large-scale criminal incidences or situations of armed conflict. Given the large numbers of people that may be impacted by a disaster, the considerable potential for property damage and the risk to social cohesion in the aftermath of a disaster, effectiveness of cross-border PPDR operation or international mutual aid could be largely beneficial.

The above operational scenarios are found in one or a number of the following domains, which also have an impact on the definition of requirements for the equipment including communications systems [6]:

- **Urban environment.** Identifies an area in a city or a densely urbanized area. It has usually high density of people and buildings. Emergency crisis and other types of PS scenarios in an urban environment are often characterized by a limited area of operation (hundreds of meters to few km), presence of man-made obstacles and need for a high reaction speed. Urban environment may have many facilities, but traffic congestion may limit the mobility of PPDR responders.
- **Rural environment.** Identifies an area, which is not densely urbanized like countryside, mountains, hills or forest areas. There may be natural obstacles like mountains and hills. An emergency crisis in a rural area may be quite large for the geographical extension (tens of square kilometer). A rural environment does not have usually an extensive communications infrastructure.
- **Blue and/or green borders.** Identifies the border between land and sea or a major lake (blue border) or between two and more different political regions in the land (green border). We can make a distinction between a border included in a single political or governmental region (i.e. national context) and a border across different political or governmental regions (i.e. cross-national context). Because different PPDR organizations are likely to operate in the second case, interoperability requirements may be more relevant.
- **Port or airport.** A port or airport has similar features to the urban environment as it is usually limited in size (few square kilometer). In comparison to a generic urban environment, there is a larger presence of critical facilities (e.g. traffic control centre) which should be protected or whose services should be maintained. Critical facilities like deposit of dangerous materials with inflammable or chemical substances may also be present.

The following dimensions are useful to capture the characteristics that are relevant to PPDR communications used in the different operational scenarios:

- **Geographical extension.** This dimension describes the size of the area involved in the emergency crisis.
- **Environment complexity.** This dimension represents the complexity of the emergency crisis in terms of number of entities involved, difficulty of the environment and so on.
- **Crisis severity.** This dimension represents the risk for the security of the citizens, infrastructures and environment.

Most day-to-day operations are conducted in low-/medium-coverage extensions and show a low environment complexity (i.e. personnel from a single agency involved) and the crisis severity is low. In turn, a natural disaster such as a flooding or an earthquake is likely to affect a large regional area and requires a complex emergency response (i.e. involving a number of PPDR agencies, volunteers and militaries), and infrastructures (e.g. transportation, communications) can be severely degraded or destroyed during a natural disaster.

1.3.2 Framework for PPDR Operations

PPDR operations usually involve [9]:

- **Intervention teams on the field**, composed of first responder officers carrying out their professional core missions and tasks (e.g. law enforcement, firefighting, medical assistance, search and rescue).
- **Intervention team leaders on the field** (integrated in intervention teams or in mobile command rooms). The leader must have the intelligence of the mission and the way to perform it. As to radiocommunications employed in the operation, team leaders master the radio scheme of their mission, for example, who has to speak with whom and on which talk groups.
- **Dispatchers or operators in the control rooms**, supporting the intervention teams on the field and their leaders in the execution of their professional core missions and tasks as well as by managing their radiocommunications (e.g. patching of talk groups). Control rooms, also referred to as emergency control centres (ECCs), are operational centres typically deployed per PPDR service/discipline (e.g. police, EMS, firefighting have separate control rooms). Control rooms house a number of operational systems including radio dispatcher terminals, computer-aided dispatching (CAD) systems for coordination and control, information systems (e.g. Geographical Information Systems (GIS)) and integrated communication control systems with connectivity to other control rooms and networks.
- **Back-office support teams** (e.g. network operator, manufacturers), which are not directly involved in the operations with first responders, but are responsible for the technical–operational conception, design and implementation of the radiocommunication systems that first responders use (e.g. data bases pre-provisioning, adjustment of technical–operational parameters, technical maintenance).

An emergency can be handled by a single PPDR agency, or it may require the participation of a number of them. Agencies involved in the emergency can be in charge of the same or different services (e.g. an emergency situation requiring only police forces vs. an emergency where police, fire and EMS are involved). Moreover, the involved agencies may be acting in their own jurisdiction or be displaced from other jurisdictions to assist in an incident (e.g. local, regional, national). The resulting combinations can lead to the following hierarchy levels of communications [5]:

- **Intra-agency communications**, thus involving a single PPDR service/single jurisdiction
- **Inter-agency communications**, involving (i) single PPDR service/multiple jurisdictions, (ii) multiple PPDR services/single jurisdiction and (iii) multiple PPDR services/multiple jurisdictions

These hierarchical levels define increasingly complex communications interactions and administration as the hierarchy moves from the single PPDR service/single jurisdiction situation to the multiple services/multiple jurisdictions events. Interoperability is key for inter-agency coordination. Interoperability impacts on the organizational and procedural aspects as well as on technical means (e.g. communications systems) used by the involved agencies. Technology provides tools to improve the effectiveness and efficiency when handling the tasks and procedures but can never replace the responsibility of the authorities and PPDR agencies and the correct application of their agreed procedures in the event of an incident. Inter-agency interoperability can be classified in the following three modes of operation [5]:

1. **Day to day.** This includes routine operations with neighbouring agencies to provide support or backup. This form of interoperability makes up the most of an individual first responder's multi-agency activities.
2. **Task force.** The task force mode defines a cooperative effort between specific agencies with extensive pre-planning and practice of the operation. This includes cooperative efforts among mixed yet specific agencies and services such as operations that are planned or scheduled and are proactive and operations that have a common goal, common leader and common communications.
3. **Mutual aid.** The mutual aid mode describes major events with large numbers of agencies involved, including agencies from remote locations. Their communications are not usually well planned or rehearsed. The communications must allow the individual agencies to carry out their missions at the event, but follow the command and control structure appropriate to coordinate the many agencies involved with the event. This could be needed in a major event that causes a large number of agencies to respond from multiple jurisdictions. Considerable coordination is required.

Considering that the majority (as much as 90% according to Ref. [13]) of the communications usage falls under the day-to-day operations mode, the communications systems must support the day-to-day operations with all the same performance features that may be required to support the other modes of operation. Unless the systems provide the first responders with seamless functionality regardless of the mode of operation, the first responders will not use their systems efficiently or effectively, especially when they need to operate in the task force and mutual aid modes.

PPDR operations follow a strict command and control hierarchy. In the context of an important event (disaster-like), incident command structures (ICS) are established. An ICS, regardless of national variations, can be typically divided into three discrete levels of management [8]: strategic overview, tactical management and operational implementation. The scope of each level is outlined in Table 1.1.

In various countries and indeed organizations within national boundaries, these structural levels have been designated with names to enable their easy identification: Gold/Silver/Bronze or Level 1/Level 2/Level 3 is the terminology commonly used. 'Gold', 'Silver' and 'Bronze' are titles of functions adopted by each of the emergency services and are role, not rank, related (i.e. titles do not convey seniority of service or rank, but depict the function carried out by that particular person). In high-profile incidents, particularly those such as terrorist incidents where there is a significant national/political involvement, it is not unusual for some to attempt to define a 'super-strategic' or 'platinum' level above the three levels described previously.

Table 1.1 Common levels of management in a command and control hierarchy.

Command and control levels	Functions
Strategic overview ('What should we do?')	<p>Determines the strategic issues relevant to the incident</p> <p>Defines the critical issues defines/records the strategy for the incident</p> <p>Ultimately provides liaison between the emergency services and key authorities (local, regional and national) and other relevant bodies, dependent on the nature of the incident</p> <p>Delegates' management of the incident to the tactical level</p>
Tactical management ('How do we achieve it?')	<p>Defines and directs the tactical parameters for managing the incident</p> <p>Plans and coordinates tasks and agencies</p> <p>Obtains resources</p> <p>Remains detached from the incident itself – must not get involved at operational level</p>
Operational implementation ('I'm doing it!')	<p>Controls and deploys resources either by geographic delineation or functional role for their respective service</p>

It is possible that, early on in the incident, members of one PPDR service will spontaneously carry out tasks normally under the responsibility of another. As soon as sufficient staff arrives, each service is expected to establish unequivocal command and control of functions for which it is normally responsible. Therefore, each of the first responder disciplines may have its own branch commanders at a large incident. As the incident progresses, it is essential that these branch commanders are able to coordinate, communicate and share information among them.

Command and control of functions are likely to be discrete in the early stages of an incident. As the incident progresses, at some stage they may move (certainly at strategic level) into one central location. At the tactical level, there may be a combination of discrete, technologically combined or physically co-located control centres, depending on a number of factors including technological systems in use, geographical location and the actual nature of the incident. The high command levels are usually operating outside the affected area.

The formation of both a Gold and Silver coordinating group can be of great value at all major incidents. Therefore, at some point during the early part of the operation, one or more tactical-level mobile control centres may be established at designated locations. Each of these should have direct voice/data communications links back to their respective permanent control centres. The staff with these mobile control centres would take control of the personnel dealing with the incident and inform the strategic-level command structure on the progress being made to address the strategy for the incident.

Some major incidents may be so quickly resolved that there is no requirement to convene a Gold coordinating group. Where a Gold coordinating group is convened, it initially consists primarily of the police, fire brigades and EMS services [8]. Additional Gold level representation from other agencies will be dependent upon the requirements of the incident (e.g. nature scale and dynamics).

The command and control structure should allow PPDR personnel to work seamlessly on situations that may begin small, but can evolve into large incidents requiring many resources

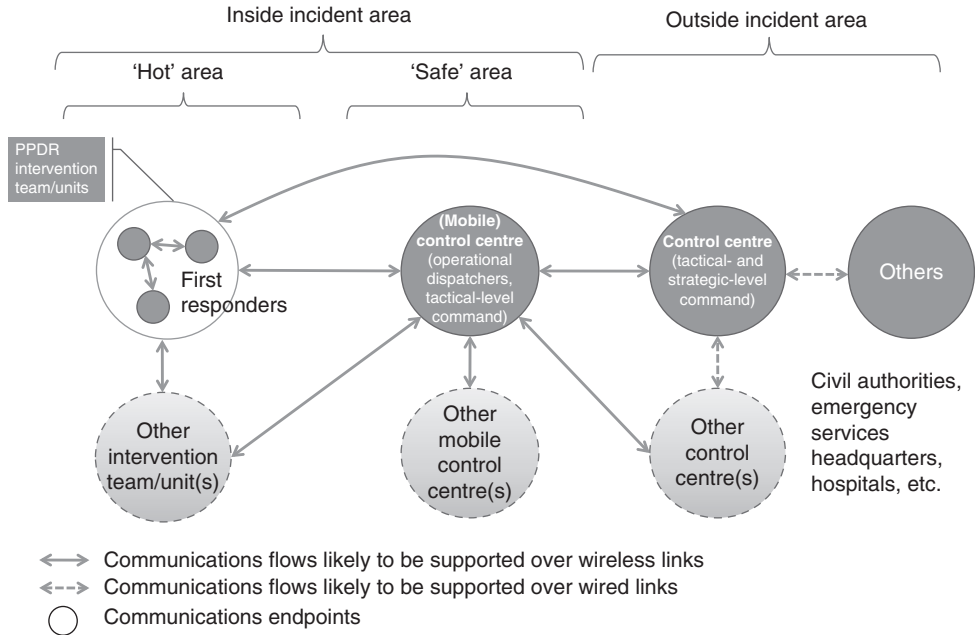


Figure 1.2 Illustrative view of potential communications flows in a common incident command structure.

and assistance from numerous jurisdictions. As an incident grows in magnitude, the incident commander has to know what resources and capabilities are becoming available for use and, if necessary, request the temporary assistance of personnel and equipment of other agencies. PPDR services are required to develop working arrangements according to circumstances.

Based on the earlier considerations, it becomes evident that multiple voice and data communications flows maybe required among intervention teams/units on the field, potentially belonging to different PPDR agencies, tactical-level mobile control centres established at designated locations within the incident area and tactical- and strategic-level control centres in remote locations outside the incident area. Figure 1.2 illustrates some of these potential communications flows in a typical ICS, distinguishing those likely to be supported over radio links from those provided over wired links and systems.

1.3.3 Communications' Reference Points in PPDR Operations

A comprehensive generic model that captures the major components and reference points between PPDR responders, authorities and other entities that may be involved in routine or emergency situations has been developed within the ETSI Special Committee on Emergency Communications (ETSI SC EMTEL) [3]. The model is illustrated in Figure 1.3.

A central component of the model is the ECC. ECCs are operational centres typically deployed per PPDR service/discipline (e.g. police, EMS, firefighting) that house a number of operational systems (e.g. dispatcher consoles, CAD and GIS tools) and are interconnected to other ECCs and a variety of networks (e.g. public telephone networks, Internet).

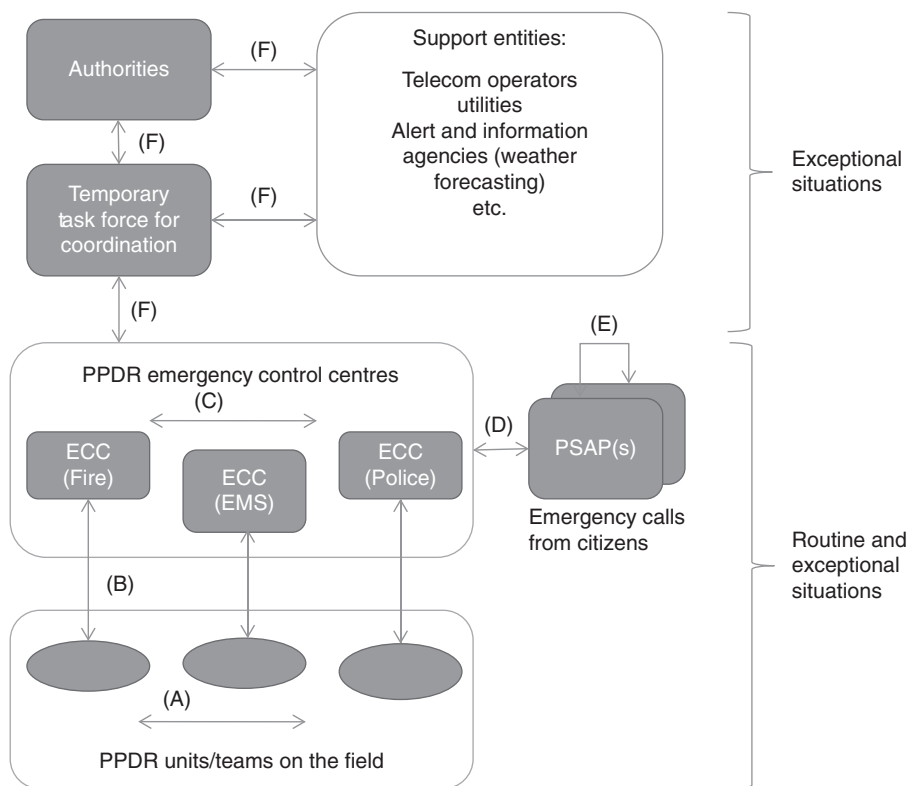


Figure 1.3 Components and reference points in PPDR communications.

Another central element in emergency handling is the so-called public safety answering point (PSAP). The PSAP is a physical location where emergency calls from citizens are received and, if necessary, forwarded to the competent ECC(s).

In exceptional situations (e.g. large emergencies and disasters), special task force or temporary headquarters can be established for emergency coordination so that communications are needed among these temporary facilities and ECCs and intervention teams on the field. Also, the involvement of public authorities (local, regional, national) may be required as well as the coordination with other non-PPDR entities that may also have a central role in the emergency response (e.g. telecom operators, utilities, information agencies such as weather forecasting, media, etc.).

The kind of actions that require communications and the main communications needs across the reference points depicted in Figure 1.3 (i.e. points tagged from (A) to (F)) are described in the following:

Communications among PPDR Unit/Teams on the Field: (A)

The intervention teams (also referred to as mobile teams) need facilities for communication among team members as well as for communications with other mobile teams. The need is for

communication across the services involved, as well as within each service. Communications at this level mainly aim at the following:

- Management of the teams and operational coordination
- Reassessing on a continuous basis the overall situation and the priority of the missions
- Enabling the reporting within the teams
- Enabling the teams to call for additional support and other resources
- Exchanging information for guidance of the staff on the spot, assessment of the injuries and preparation of fixed rescue facilities before arrival of injured people

Officers on the field have to spend a minimum of time and capacity with radio transmission. Therefore, the radio procedures they apply must be kept as simple as possible (e.g. terminal manipulations, like talk group selection, shall be strictly limited).

The intervention team leader(s) on the field (integrated in intervention teams or in mobile command rooms) must have the intelligence of the mission and the way to perform it. In particular, besides the basic officer radiocommunication knowledge, they need to master the radio scheme of their mission, that is, who has to speak with whom and, in application of a functional radio model, on which talk groups.

Interoperability between the communications systems in use is essential. In addition, fall-back communications service needs to be available to the field teams in cases where network service is either unavailable or disturbed due to the nature of the emergency/disaster.

Communications among ECCs and Intervention Units/Teams on the Field: (B)

The access to permanent bidirectional communications links between ECCs and their mobile teams is crucial in the handling of emergencies. These communications links enable the same kind of functions discussed previously for communications among teams but now involve PPDR personnel on control rooms (e.g. operational dispatchers, tactical/strategic-level commanders) as well as the use of supporting tools and systems (e.g. GIS-based applications) that can greatly improve emergency response.

Dispatcher(s) or operators in the control rooms give support to the intervention teams on the field and their leaders in the execution of their professional core missions and tasks. Depending on the governance model, dispatchers will only assist and coordinate the teams on behalf of an end chief or will also have the lead on them. Dispatchers also give support by managing the radiocommunications used by intervention teams. Therefore, dispatchers must have a solid understanding of the functional radio model and the related operational radio procedures to face an evolving or an unexpected situation.

Through the ECC, communications can be established between all involved parties (mobile team members, control room staff, receiving and assisting units/institutions). Among the main features needed for this type of communications are:

- Seamless radio coverage throughout the affected area, including guaranteed availability of coverage also under exceptional conditions as well as means to maintain communication during network outage.
- Enough traffic capacity at the incident. The need for radio capacity is increasing during major incidents and accidents. Efforts have to be made to ensure as far as possible that sufficient communications facilities are available.
- Sufficient voice quality not to impair the understanding of the message.

- Specialized features at the disposal of dispatchers to regulate, in real time, the radiocommunications such as combining (patching) of groups, remotely programming extra groups on terminals and remotely selecting groups on terminals. In addition, access to the network shall be controlled by using functionalities such as assigning priority to potential users, thereby restricting some parties from access to the network under certain circumstances.

Communications among ECCs: (C)

ECCs need to have the facilities to collaborate with other ECCs, either within the same service or across services (e.g. between fire and EMS). Interconnection of ECCs may rely on the use of fibre-optic, microwave, and copper landline systems to provide backbone links for voice and data applications. Examples of cases where this is needed are:

- Callers are transferred to the wrong ECC so that the call needs to be forwarded to the correct ECC together with additional information (e.g. location data).
- Cases involving more than one ECC (e.g. fires with risks for human lives that typically involve fire, health and police, CBRN incidents (or suspected incidents), terrorism).
- The communications facilities exist to integrate the resources from two or more ECCs, in case of a larger emergency situation.

Communications requirements among ECCs must:

- Establish communications links to support a number of services, including speech and data.
- Conform to the relevant procedures established by the ECCs or their organizations.
- Support conference calls including external resources that may need to be set up and kept over a substantial amount of time. In contingencies, calls to external resources may be required.

Communications among ECCs and PSAPs: (D)

PSAP and ECC are two different functionalities that may or may not be integrated. The PSAP will, after reception of an emergency call from an individual/citizen, communicate without delay with the competent ECC and transmit the location and nature of the emergency of the calling party along with any other relevant information that may be available associated with the call.

For this purpose, reliable and pre-planned communications links among all of the ECCs in the competence zone of the emergency situation must enable to transmit voice and transfer all the data received at the PSAP (especially location data) or collected by the operator of the PSAP.

Communications among PSAPs: (E)

PSAPs normally work independently and their interrelation is not subject to special needs.

In cases where calls arrive at another PSAP than the one responsible for the area where the call is originated (e.g. mobile phones in the bordering area between different PSAPs), there may be a need to transfer the call together with additional information (e.g. location data). The need will depend upon the operation rules that have been established for these types of situation, for example:

- The call is handled by the receiving PSAP (e.g. the immediate help is a key point in the case, the case of PSAP backup, or load sharing).
- The call is immediately transferred to the normal PSAP, which handles all the case. In such a scenario, the location data must remain accessible to the normal PSAP, as for any received call.

- Depending on local procedures, the receiving PSAP may transfer the call directly to the relevant ECC, possibly together with information to the correct PSAP that the call has been transferred.

It is the responsibility of the PSAPs or their organization to predefine these rules of procedures.

Communications among Special Task Force or Temporary Headquarters and Permanent Entities in Special Conditions: (F)

For their efficient work in handling emergencies, special task force or temporary headquarters and ECCs are depending on access to permanent bidirectional links with the mobile teams and temporary headquarters. This access needs to be available for the duration of the emergency/disaster. The basic need is for configurable communications, to fulfil all contingency plans for, under the possible stages of escalation for a simple emergency situation, through a crisis to a regional or national disaster.

A much more extended description of the functional requirements for communications for all of the earlier reference points in PPDR communications can be found in Refs [3, 9].

1.3.4 Communications Services Needed for PPDR Operations

PPDR communications have to be effective, fast, reliable, secure and interoperable where possible, in order not to put at risk the success of PPDR operations. The efficiency of the emergency operation is dependent upon the ability of the communications network to deliver a real-time exchange of information between several authorized emergency personal. As discussed in the previous subsection, this can occur at various levels in the emergency situation, for example, between agents on the field, between officers in the ECCs and the agents on the field and, in major incidents, between any established temporary coordination headquarter and the involved ECCs.

To emphasize the criticality of PPDR communications needs, two types of operational situations addressed by PPDR organizations are typically defined [10]:

1. **Mission-critical situations.** The expression ‘mission critical’ is used for situations where human life, rescue operations and law enforcement are at stake and PPDR organizations cannot afford the risk of having transmission failures in their voice and data communications or for police in particular to be ‘eavesdropped’.
2. **Non-mission-critical situations.** This refers to situations where communication needs are non-critical: human life and properties are not at stake, administrative tasks for which the time and security elements are not critical, etc.

Therefore, it can be stated that mission-critical communications refer to any information transfer that becomes crucial to the successful resolution of a PPDR operation.¹ Table 1.2

¹ The distinction between ‘mission critical/non-mission critical’ is sometimes considered an oversimplification of what it could really be a hierarchy or continuum of criticality extending from minor incidents to international catastrophes [14]. Moreover, this terminology is not specific to the PPDR sector but also used in other areas such as the critical infrastructure sectors (e.g. energy, transportation, etc.). A more transversal definition of ‘mission critical’ is proposed in Ref. [14]: ‘A mission is “critical” when its failure would jeopardise one or more human lives or put at

Table 1.2 High-level classification of required communications services.

Service	Interactivity level	Description
Voice	Interactive	Interactive voice communications between public safety practitioners and their supervisors, dispatchers, members of the task force, etc. require immediate and high-quality response and must meet much higher-performance demands than those required by commercial users of wireless communications. Commands, instructions, advice and information are exchanged that often result in life-and-death situations for public safety practitioners, as well as for the public.
	Non-interactive	Non-interactive voice communications occur when a dispatcher or supervisor alerts members of a group about emergency situations or acts to share information, without an immediate response being required or designed in the communications. In many cases, the non-interactive voice communications have the same mission-critical needs as the interactive service
Data	Interactive	Interactive data communications mean that there is query made and a response provided. Such communications can provide practitioners with maps, floor plans, video scenes, etc. A practitioner may not need to initiate the query and response; it can include automated queries or responses. A common form of interactive data communications is instant messaging. Commanders, supervisors, medical staff, etc., can make intelligent decisions more efficiently with data from field personnel. Similarly, personnel entering a burning building armed with information about the building, such as contents, locations of stairwells, hallways, etc., can also perform their duties more efficiently
	Non-interactive	Non-interactive data communications are one-way streams of data, such as the monitoring of firefighter biometrics and location, etc., which greatly increase the safety of the practitioners. This form of communications also makes command and control easier because a commander is aware of the condition and location of the on-scene personnel

provides a common classification of the communications services that public safety agencies (PSAs) require to handle mission-critical operations [5]. The classification distinguishes between voice and data services and, for each of them, the level of interactivity required. Voice is so far the most important communications mechanism for mission-critical operations, though it is worth noting that over time the definition of mission critical will remain ever changing and the demands of tomorrow's first responders may change. In fact, data communications are becoming increasingly important to PPDR practitioners to provide the information needed to carry out their missions so that some data applications will likely become mission critical in the future. Additional details on voice and data services are provided in the following subsection.

risk some other asset whose impairment or loss would significantly harm society or the economy. In such cases even small degradations of communication supporting the mission could have possibly dire consequences'. For instance, in the utility and transport sectors, preventing socioeconomic damage above some agreed levels could be defined as a 'critical mission' (in addition to preventing injury or loss of life), while damage below agreed levels might at most be 'business critical' (affecting specific individuals or firms but not enough to harm society or the wider economy).

1.3.4.1 Voice Services

The term mission-critical voice has been used within the PS community for decades, but there has been no one single complete definition of what, exactly, mission-critical voice is. In an effort to provide a basis for a common understanding of the meaning of and the multiple requirements of mission-critical voice, the following key elements for the definition of mission-critical voice have been recently identified [15]:

- **Direct or talk around.** This mode of communications provides PS with the ability to communicate unit to unit when out of range of a wireless network or when working in a confined area where direct unit-to-unit communications is required. In this way, responders can talk even when network infrastructure is unavailable.
- **Push to talk (PTT).** This is the standard form of PS voice communications today: the speaker pushes a button on the radio and transmits the voice message to other units. When they are done speaking, they release the PTT switch and return to the listen mode of operation.
- **Group call or talk group.** This method of voice communications provides communications from one-to-many members of a group and is of vital importance to the PS community.
- **Full duplex voice systems.** This form of voice communications mimics that in use today on cellular or commercial wireless networks where the networks are interconnected to the public switched telephone network (PSTN).
- **Talker identification.** This provides the ability for a user to identify who is speaking at any given time and could be equated to the caller identification feature available on most commercial cellular systems today.
- **Emergency alerting.** This indicates that a user has encountered a life-threatening condition and requires access to the system immediately and is, therefore, given the highest level or priority.
- **Audio quality.** This is a vital ingredient for mission-critical voice. Audio quality must ensure voice to be intelligible in the difficult noise environments that first responders might encounter. The listener must be able to understand without repetition, identify the speaker, detect stress in a speaker's voice and hear background sounds as well without interfering with the prime voice communications.

1.3.4.2 Data Services

While voice communications will remain a critical component of PPDR operations, new data and video services are expected to play a key role increasingly. For instance, PPDR agencies today already use applications such as video for surveillance of crime scenes and of highways as well as to monitor and conduct damage assessment of wild land fire scenes from airborne platforms that can provide real-time video back to ECCs. In addition, there is a growing need for full motion video for many other uses such as situational awareness from intervention teams or the use of robotic devices in human life-threatening conditions.

Indeed, data services can be used to provide a large number of applications, which can have widely differing requirements in terms of capacity, timeliness and robustness of the underlying data communications service. As an illustrative example, Table 1.3 provides a list of

Table 1.3 Data applications and associated requirements.

Service	Throughput	Timeliness	Robustness
E-mail	Medium	Low	Low
Imaging (e.g. picture transfer)	High	Low	Variable
Digital mapping/geographical information services	High	Variable	Variable
Location services	Low	High	High
Video (real time)	High	High	Low
Video (slow scan)	Medium	Low	Low
Data base access (remote)	Variable	Variable	High
Data base replication	High	Low	High
Personnel monitoring	Low	High	High

potential data-centric applications for PPDR use as identified in Ref. [3], which have been characterized in terms of their impact on network throughput (i.e. data bit rate), timeliness (i.e. responsiveness) and robustness (i.e. reliability).

Some applications may be used with dedicated communications assets tuned to the particular needs of that application, although interfaces may be necessary to exchange data from such dedicated systems with other applications. Where appropriate, such applications should be based on appropriate standards to facilitate information exchange among them. Where data applications share the use of a data transmission capability, the provision of sufficient capacity and effective management must be provided to ensure application data is communicated appropriately.

1.4 Communications Systems for PPDR

This section describes the main communications technologies and systems currently in use for the delivery of the communications services needed for PPDR operations discussed in the previous section. In this regard, a review of the type of requirements usually bound to PPDR communications systems is provided in the first subsection. Afterwards, a common classification of the technologies based on achievable bit rates (narrowband (NB), wideband (WB) and broadband (BB)) is presented, pointing out the main standards that fit in each category. The classification is then followed by an overview of the most widely used digital radio-communication standards for PPDR communications as of today (Terrestrial Trunked Radio (TETRA), TETRAPOL, DMR, P25). Finally, the section is concluded with the identification of some of the major limitations found in today's PPDR communications landscape through the analysis of an illustrative, hypothetical incident.

1.4.1 General PPDR Requirements on Communications Systems

Due to its unique operational requirements, PPDR has multiple complex communications technology needs. These requirements involve communications solutions that in some cases are unique to PPDR. General requirements for PPDR communication systems have been

widely discussed [1, 3, 5]. A comprehensive view of the type of requirements that should be accounted for are given in the following:

- **Service capabilities and performance.** Central service capabilities required for PPDR are PTT operations, broadcasting/group communications and talk around (i.e. direct mode, terminal to terminal) for voice communications. There may be additional requirements in terms of data services (e.g. status messaging, short messaging, automatic vehicle location (AVL) and tracking) and supplementary services such as ambience listening, dynamic group number assignment (DGNA), call authorization by dispatchers, late entry and many others. Fast responsiveness and low latency requirements are typically required for these services (e.g. fast call set-up below 300 ms and end-to-end voice delay in the range of 200 ms). The equipment in use is typically required to support most of these service capabilities, while the user is in motion. The equipment may also require high audio output (to overcome high-noise environment); unique accessories, such as special microphones; operation while wearing gloves; operation in hostile environments (heat, cold, dust, rain, water, shock, vibration, explosive environments, etc.); and long battery life.
- **Strict control of the communications means.** This includes centralized dispatch for coordination and control of communications channels within the PPDR system together with the administration of terminal, subscriber and group call settings (e.g. group monitoring, dynamic regrouping, etc.). This also encompasses the support of prioritization mechanisms to make sure that important calls are always treated first in case of system congestion. The supported priorities may be required to reflect a hierarchy (among people or departments) but also an operational situation requiring special treatment of the call, whatever the hierarchy of the person. Prioritization may include pre-emptive emergency call capabilities, overriding if necessary ongoing low priority communications.
- **Security-related requirements.** Efficient and reliable PPDR communications within a PPDR organization and between various PPDR organizations, which are capable of secure operation, may be required. Security requirements may cover the need for subscriber/network authentication and support of encryption and integrity mechanisms over the radio interface and, in some cases, even require the use of end-to-end encryption (E2EE) between the endpoint terminals. Notwithstanding, there may be occasions where administrations or organizations, which need secure communications, bring specific equipment to meet their own security requirements. Furthermore, it should be noted that many administrations have regulations limiting the use of secure communications for visiting PPDR users.
- **Coverage.** The PPDR system is usually required to provide complete coverage for 'normal' traffic within the relevant jurisdiction and/or operation (national, provincial/state or at the local level). This coverage is required 24 h/day, 365 days/year. Usually, the systems supporting PPDR organizations are designed for peak loads and wide fluctuations in use. Additional resources, enhancing system capacity, may be added during an incident by techniques such as reconfiguration of networks with intensive use of direct mode and vehicular repeaters, which may be required for coverage of localized areas. Systems supporting PPDR are also usually required to provide reliable indoor and outdoor coverage, coverage in remote areas and coverage in underground or inaccessible areas (e.g. tunnels, building basements). Coverage requirements can be specified as, for example, 99.5% (outdoor mobile) and 65% or better (indoor mobile). Appropriate redundancy to continue operations when the equipment/infrastructure fails is extremely beneficial. PPDR systems are not generally installed

inside numerous buildings. PPDR entities do not have a continuous revenue stream to support installation and maintenance of an intensive variable density infrastructure. Urban PPDR systems are designed for highly reliable coverage of personal stations outdoors with limited access indoors by direct propagation through the building walls. Subsystems may be installed in specific building or structures (e.g. tunnels) if penetration through the walls is insufficient. PPDR systems tend to use larger radius cells and higher-power mobile and personal stations than commercial service providers.

- **Capacity.** Very low call blocking levels are typically required in PPDR systems (e.g. well below 1% under worst-case dimensioning assumptions). The system capacity must be sufficient to manage the anticipated traffic and yet be flexible enough in its functional design to also support communication during 'surge' conditions which exceed the anticipated traffic, for example, by using additional transportable switch and base stations. Sufficient data bandwidth may be also required to support a wide variety of data applications. Noting the extreme circumstances that may be in force during an emergency, it may be desirable for networks to degrade gracefully when user requirements exceed the normal levels of service.
- **High levels of service availability.** Service availability relates to the amount of time (usually per year) that a service is up and running. It is commonly measured in 'nines' of availability (e.g. 99.9 or 99.99% availability at all times is a typical requirement for PPDR applications). The achievement of high levels of service availability may require several layers of redundancy as well as resilient and robust equipment (e.g. hardware, software, operational and maintenance aspects).
- **System reconfiguration.** A rapid dynamic reconfiguration of the system serving PPDR may be required. This includes robust operation, administration and maintenance (OAM) systems offering status and dynamic reconfiguration. For instance, system capability to reprogramme field units over the air could be extremely beneficial.
- **Interconnection.** While PPDR systems are mainly intended to provide private, in-system communications, appropriate levels of interconnection to public telecommunications networks may also be required. The decision regarding the level of interconnection (i.e. all mobile terminals vs. a percentage of terminals) may be based on the particular PPDR operational requirements. Furthermore, the specific access to the public telecommunications network (i.e. directly from mobile or through the PPDR dispatch) may also be based on the particular PPDR operational requirements.
- **Interoperability.** Communications interoperability might be required at different levels of a PPDR operation, from the most basic level, that is, a firefighter of one organization communicating with a firefighter of another, up to the highest levels of command and control. Usually, coordination of tactical communications between the on-scene or incident commanders of multiple PPDR agencies is required. Remarkably, the achievement of the desired interoperability is not only a technical matter but spans from organizational and operational aspects to regulatory and legal frameworks. Mainly from a technical perspective, various options are available to facilitate communications interoperability between multiple agencies. These include, but are not limited to, the use of common frequencies and equipment, communication via dispatch centres/patches, interconnection of the PPDR networks via wire line interfaces or utilizing technologies such as radio gateways (e.g. 'back-to-back' gateways or relays) or more advanced software-defined radio (SDR) equipment.

- **Spectrum usage and management.** Depending on national frequency allocations, PPDR users must share with other terrestrial mobile users for some applications (e.g. point-to-point radio links). The detailed arrangements regarding sharing of the spectrum vary from country to country. Furthermore, there may be several different types of systems supporting PPDR operating in the same geographical area. Therefore, interference to systems supporting PPDR from non-PPDR users should be minimized as much as possible. Depending on the national regulations, the systems supporting PPDR may be required to use specific channel spacing between mobile and base station transmit frequencies. Each administration has the discretion to determine suitable spectrum for PPDR.
- **Regulatory compliance.** The systems supporting PPDR should comply with the relevant national regulations. In border areas (near the boundary between countries), suitable coordination of frequencies should be arranged, as appropriate. The capability of the systems supporting PPDR to support extended coverage into the neighbouring countries should also comply with regulatory agreements between the neighbours. For DR communications, administrations are encouraged to adhere to the principles of the Tampere Convention. Flexibility should be afforded to PPDR users to employ various types of systems (e.g. HF, satellite, terrestrial, amateur, Global Maritime Distress and Safety System (GMDSS)) at the scene of the incident in times of large emergencies and disasters.
- (Last but not least) **Cost-related requirements.** Cost-effective solutions and applications are extremely important to PPDR users. The deployment of dedicated PPDR networks is usually very demanding for PPDR organizations from an economic point of view. A national or regional network is usually an investment for 10–15 years or more. This can be facilitated by open standards, a competitive marketplace and economies of scale. Furthermore, cost-effective solutions that are widely used can reduce the deployment and upgradeability costs of permanent network infrastructure. Administrations should consider the cost implications of interoperable equipment since this requirement should not be so expensive as to preclude implementation within an operational context.

It is noted that individual administrations or PPDR organizations may have their own requirements for PPDR that go beyond those described herein and that each standard would need to be evaluated on a case-by-case basis against those requirements.

1.4.2 Technologies in Use for PPDR Communications

A common classification of technologies used for PPDR communications is based on the average data rates required by the supported PPDR applications [1]:

- **Narrowband (NB).** It refers to technologies mainly intended to deliver voice-centric communications and low-speed data applications. Typical data rates are up to a few tenths of kilobits per second, operating on radio-frequency channels of up to 25 kHz. Current state of the art in the PPDR sector are digital radio trunking technologies such as TETRA, TETRAPOL and Project 25 (P25), which are commonly used to deploy wide area coverage networks. These technologies are typically referred to as professional/private mobile radio (PMR) technologies (the term land mobile radio (LMR) is also common in North America), though it's worth noting that PMR technologies are not only used in the

PPDR sector but also adopted in many other markets such as transportation, utilities, industry, private security and even military. A further insight into the main NB PMR standards used for PPDR communications is addressed in Section 1.4.3

- **Wideband (WB)**. It refers to technologies that can deliver application data rates of several hundreds of kilobits per second (e.g. in the range of 384–500 kb/s). Systems for WB applications to support PPDR have been or are underdevelopment in various standards organizations. The most significant example in the context of PPDR is the evolution of TETRA, known as TETRA Enhanced Data Service (TEDS), that adds support for more efficient modulations and the use of radio-frequency channels of up to 150 kHz wide. Nevertheless, WB technologies have not been yet widely deployed as their NB counterparts. The point is that WB technology is currently regarded as not sufficient to meet future PPDR demands so that the natural upgrade from NB to WB technology is likely to be bypassed. A migration path from NB to BB and their coexistence is as of today the most likely migration scenario.
- **Broadband (BB)**. It refers to technologies that enable an entirely new level of functionality with additional capacity to support higher-speed data communications than WB, likely including high-resolution video transmission. Initially, the use of BB technologies was mainly intended to support PPDR operations in localized areas (e.g. 1 km² or less), providing indicative data rates in the range of several megabits per second. Localized operational scenarios open up numerous new possibilities for PPDR applications, including tailored area networks, hot spot deployment and ad hoc networks. In this regard, specialized communications gear such as tactical networking equipment [16] intended to fulfil PPDR responders' needs is already available, though its adoption by PPDR practitioners is very limited (its use is basically confined to the military domain). These communications systems are typically based on Wi-Fi-like radio interfaces and can operate in open bands, such as the 2.4- and 5.8-GHz Wi-Fi bands, and/or on restricted bands, such as the 4.4-GHz (allocated to military use in some countries) and 4.9-GHz bands (allocated to PPDR use in some countries). However, in addition to localized service, the demand for BB applications is now importantly shifting towards wide area coverage. In this context, the current mainstream commercial Long-Term Evolution (LTE) technology ecosystem is consolidating as the 'de facto' standard for the delivery of mobile BB PPDR applications.

Table 1.4 gives an overview of the various PPDR applications alongside the particular feature provided and specific PPDR examples of use, as developed in Report ITU-R M.2033 [1]. The applications are grouped under the NB, WB and BB headings to indicate which technologies are most likely to be required to supply the particular application and their features. Application types listed in the table can be used in any of the operational environments described in Section 1.3.2. The detailed choice of PPDR applications and features to be provided in any given area by PPDR is a national or operator-specific matter.

1.4.3 Current NB PMR Standards Used in PPDR

The requirements of the PPDR community for mission-critical voice and data services are currently satisfied by a range of voice-centric NB technologies such as TETRA, TETRAPOL, DMR and P25. These are all NB digital trunking systems able to offer a wide range of

Table 1.4 PPDR applications and examples.

Application	Feature	PPDR example
1. Narrowband		
Voice	Person to person	Selective calling and addressing
	One to many	Dispatch and group communication
	Talk-around/direct mode operation	Groups of portable to portable (mobile–mobile) in close proximity without infrastructure
Facsimile	Push to talk	Push to talk
	Instantaneous access to voice path	Push to talk and selective priority access
	Security	Voice
Messages	Person to person	Status, short message
	One to many (broadcasting)	Initial dispatch alert (e.g. address, incident status)
Security	Priority/instantaneous access	Man down alarm button
	Location status	GPS latitude and longitude information
Telemetry	Sensory data	Vehicle telemetry/status
	Database interaction (minimal record size)	Electrocardiograph (EKG) in field
Database interaction (minimal record size)	Forms-based records query	Accessing vehicle license records
	Forms-based incident report	Filing field report
2. Wideband		
Messages	E-mail possibly with attachments	Routine e-mail message
Data talk-around/direct mode operation	Direct unit-to-unit communication without additional infrastructure	Direct handset-to-handset, on-scene localized communications
Database interaction (medium record size)	Forms and records query	Accessing medical records
		Lists of identified person/missing person
Text file transfer	Data transfer	Geographical Information Systems (GIS)
		Filing report from scene of incident
Image transfer	Download/upload of compressed still images	Records management system information on offenders
		Downloading legislative information
Telemetry	Location status and sensory data	Biometrics (fingerprints)
		ID picture
Security	Priority access	Building layout maps
		Vehicle status
Video	Download/upload compressed video	Critical care
		Video clips
Interactive	Location determination	Patient monitoring (may require dedicated link)
		Video feed of in-progress incident
		Two-way system
		Interactive location data

Table 1.4 (continued)

Application	Feature	PPDR example
3. Broadband		
Database access	Intranet/Internet access	Accessing architectural plans of buildings, location of hazardous materials
	Web browsing	Browsing directory of PPDR organization for phone number
Robotics control	Remote control of robotic devices	Bomb retrieval robots, imaging/video robots
Video	Video streaming, live video feed	Video communications from wireless clip-on cameras used by in building fire rescue Image or video to assist remote medical support Surveillance of incident scene by fixed or remote controlled robotic devices Assessment of fire/flood scenes from airborne platforms
Imagery	High-resolution imagery	Downloading Earth exploration-satellite images

Reproduced from Ref. [1].

voice-centric services and features but limited data capability. In addition to these digital systems, analogue systems, both conventional² and trunked, still remain operational in some places (e.g. VHF FM radios, MPT1327 systems) [17]. Nevertheless, as digital standards become more mature and more manufacturers release low-cost digital products, there is a steady migration to digital technologies, further facilitated by the fact that some of the digital standards can operate in dual mode to maintain analogue and digital compatibility and ensure an easy migration.

Within digital systems, both frequency division multiple access (FDMA) and time division multiple access (TDMA) technologies are used. Most current FDMA and TDMA products can offer the equivalent of one voice channel per 6.25 kHz of RF channel bandwidth. FDMA systems can be typically programmed to use either 6.25- or 12.5-kHz channels, while TDMA typically offers only a set of two or four voice channels (slots) carried inside a 12.5- or 25-kHz RF channel. FDMA and TDMA each have certain advantages for specific uses. For instance, an FDMA system using a single 6.25-kHz RF channel has an extra 3 decibels (dB) of sensitivity

² Conventional systems, also sometimes referred to as ‘non-trunked’ systems, possess no centralized management of subscriber operation or capability. Conventional systems allow users to operate on fixed RF channels without the need for a control channel. All aspects of system operation are under control of the system users. Operating modes within non-trunked systems include both direct (i.e. radio-to-radio) and repeated (i.e. through an RF repeater) operation. Users simply select the appropriate channel in their radios and communicate immediately with no repeater set-up time. Conventional systems may enough to meet the needs of agencies for cost-effective, low-density communications systems. On the other hand, trunked systems provide for management of virtually all aspects of radio system operation, including channel access and call routing. Most aspects of system operation are under automatic control, relieving system users of the need to directly control the operation of system elements. Unlike conventional operation in which a radio channel is dedicated to a particular user group for communications, trunking provides users access to a shared collection of radio channels. Trunked systems may be particularly attractive to agencies in communities that want to join together to form shared large-scale systems.

and less noise than other offerings in 12.5 or 25 kHz. Therefore, if there is a need to operate a voice channel over a long distance and in a noisier-than-normal RF environment, a single 6.25-kHz FDMA is likely to outperform the other radios in range and noise tolerance. On the other hand, if the requirements include mostly data communications, a TDMA radio like TETRA can offer the highest data bandwidth by aggregating the four voice channels into a single 25-kHz data channel.

PMR technologies are used in the PPDR domain to deploy from small-scale systems with only one or a few sites serving the needs of an individual agency to nationwide networks shared by multiple PPDR organizations. Indeed, in Europe, national multi-agency networks with countrywide coverage have been (some are still being) deployed in most countries based on TETRA and TETRAPOL technologies. In turn, a more complex environment is found in the United States where there is a plethora of independent systems deployed at different jurisdictional levels (municipalities, counties) and significant efforts are being undertaken in some states towards improving interoperable communications with the deployment of statewide P25 systems. Some further details on the TETRA, TETRAPOL, DMR and P25 technologies and network deployments are given in the following subsections, including a comparative view chart of their key features in Table 1.5. A more extended description of the technical and operational characteristics of several digital PMR technologies introduced throughout the world in the PPDR and other sectors can be found in the International Telecommunication Union (ITU) Report ITU-R M.2014 [18].

Table 1.5 Comparison chart of the main digital PMR technologies used for PPDR.

Feature	TETRA	TETRAPOL	DMR	P25
Technology	Four-slot TDMA	FDMA	Tier I: FDMA Tier II and III: Two-slot TDMA	Phase 1: FDMA Phase 2: TDMA
Frequencies	VHF, UHF, 800 MHz	VHF, UHF, 800 MHz	Frequency bands 66–960 MHz	VHF, UHF, 700, 800, 900 MHz
Channel bandwidth	25 kHz	12.5 kHz	12.5 kHz	Phase 1: 12.5 kHz Phase 2: 25 kHz
Data rate	28 kb/s (up to ~500 kb/s over 150 kHz channels with TEDS)	<8 kb/s	<8 kb/s	9.6 kb/s
Modulation	$\pi/4$ DQPSK	GMSK	Four-level FSK	C4FM
Vocoder	ACELP	RP-CELP	AMBE+2	AMBE+2
Encryption	TEA algorithms for AIE + specific algorithms for E2EE	E2EE. Algorithms may comply with TETRAPOL specifications or specific algorithms can be used	AES	AES/DES
More information	TETRA + Critical Communications Association (TCCA)(http://www.tandcca.com/)	TETRAPOL Forum(http://www.tetrapol.com/)	DMR Association(http://dmrassociation.org/the-dmr-standard/)	P25 Technology Interest Group (PTIG)(http://project25.org/)

1.4.3.1 TETRA

TETRA is a mature and established TDMA digital voice trunked and data radio technology used around the world. TETRA is an open standard developed by the European Telecommunications Standards Institute (ETSI). The TETRA standard was finalized in 1995 and introduced in the market in 1997. TETRA equipment is available in the VHF, UHF and 800-MHz bands. TETRA standard confers interoperability between radio equipment from multiple vendors. The TETRA and Critical Communications Association (TCCA) was established in December 1994 (known then as the TETRA MoU Association) to create a forum to act on behalf of all parties interested in TETRA technology, representing users, manufacturers, application providers, integrators, operators, test houses and telecom agencies. A TETRA Interoperability Certification process is managed by this organization to enable an open multivendor market for TETRA equipment and systems.

The TETRA standard supports many voice-centric services and facilities. Examples are group call, pre-emptive priority call (also called ‘emergency call’), call retention, priority call, busy queuing, direct mode operation (DMO), DGNA, ambience listening, call authorized by dispatcher, late entry and many others. TETRA uses the Algebraic Code Excited Linear Prediction (ACELP) vocoder. Up to four voice channels can be supported over a single RF 25-kHz channel (four-slot TDMA).

The TETRA standard also provides some data transmission capabilities. Status messaging and short data service (SDS) are simple services that allow for the exchange of short strings of bytes. In addition to sending human-readable information, these messaging capabilities are also used as transport bearer services for applications that require very low data rates such as AVL. TETRA also supports a packet data (PD) service that provides a standard IP connectivity service that can be used to support other added-value applications with relatively higher bit rates (e.g. database lookup, picture messaging). However, the delivered data rates are peaked to 28.8 kb/s, achieved when the four slots of a 25-kHz carrier are combined and data is sent with the lowest protection for error control. To improve the support for data communication in TETRA, the ETSI Board in 2005 mandated the development of TETRA Release 2, commonly known as TEDS. TEDS offers new modulation options and wider radio channels (50, 100 and 150 kHz) to support data traffic rates of up to 500 kb/s, matching the speeds provided by cellular 2G GPRS/EDGE technology.

Other remarkable features supported by TETRA are DMO gateways, DMO repeaters and ‘fallback’ modes in TETRA base stations. A DMO gateway allows relaying the communication between a TETRA DMO terminal and a TETRA network that may not be directly reachable from that terminal. A DMO does a similar relaying but now between two DMO terminals that cannot see each other. A typical application for the DMO repeater/gateway functionality is the following [19]. A DMO gateway is installed in a vehicle so that it automatically ‘bridges’ the network traffic to and from a person who left the vehicle and is working in the field, using a low-power handheld radio to talk to and from the TETRA network. With regard to the fallback mode in base stations, this allows a base station to continue to serve users if the backhaul link towards the rest of the infrastructure fails.

In terms of security, and similarly to all of the other digital PMR technologies used for PPDR communications, TETRA provides multiple security features for the verification of identities, protection of confidentiality and integrity and protection against lost or stolen

terminals. In this regard, some of the main security features within the TETRA standard are the following [20]:

- Authentication. The authentication service allows a TETRA terminal and a TETRA network to prove each other's real identity, by proving to both parties the knowledge of a shared secret key (i.e. the authentication key K), unique for each terminal and only available in the terminal and a secured server of the home TETRA network.
- Air interface encryption (AIE). The AIE service allows encrypting the 'air interface' (AI), signalling and voice, between a TETRA terminal and its serving TETRA network. The TETRA standard supports a number of over-the-air TETRA Encryption Algorithms (TEAs), the differences being the types of users who are permitted to use them. Encryption keys can be static (e.g. usually preconfigured in the terminals) or dynamic (derived per connection as needed). Over-the-air rekeying (OTAR) methods are supported in TETRA to transfer in real-time secret keys securely to terminals.
- Enable and disable. This service provides a mechanism by which a terminal can be denied or allowed access to a TETRA system.
- Support for E2EE. It allows two parties to communicate in secure mode by ciphering the whole communication data at terminal level. In this case, a variety of other encryption algorithms can be used as deemed necessary by the national security organizations.

A schematic of a TETRA network architecture showing the standardized interfaces is depicted in Figure 1.4. The core of a TETRA network, named Switching and Management Infrastructure (SwMI), consists of a number of radio base stations (RBS) interconnected through one or a hierarchy of switches and/or routers (routers would be used in the case of TETRA over IP implementations). Typical components connected to the SwMI include the network management system, control room systems such as line dispatchers, PABX/PSTN/ISDN interconnections and IP gateways for PD networks. The gateway interfaces to PSTN, ISDN and PD networks have been standardized, in addition to an Inter-system Interface (ISI)

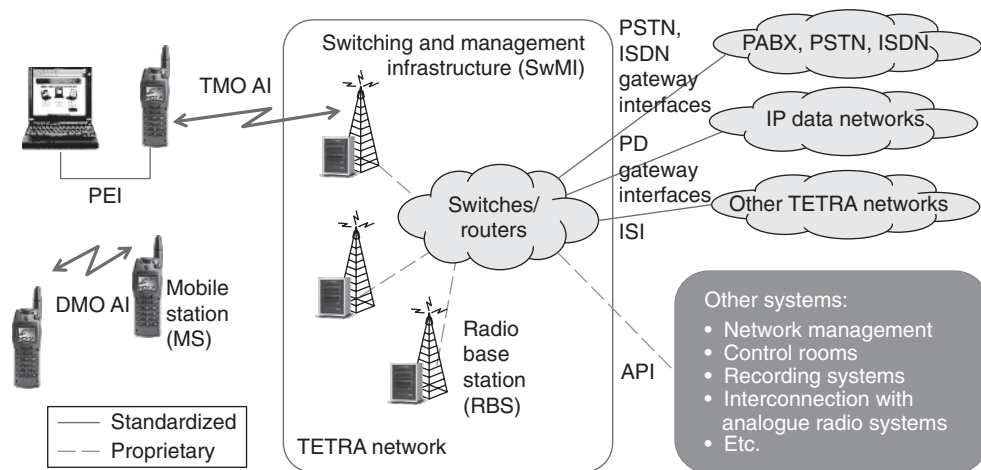


Figure 1.4 Network architecture and standardized interfaces of a TETRA system.

intended to interconnect TETRA networks. The remaining interfaces within the SwMI are proprietary implementations (vendor Application Programming Interfaces (APIs), which allow access to some of the SwMI services and functions). It is worth noting that the internal interface within the SwMI between the RBS and the switching/routing elements is not standardized either. On the radio side, two modes for the operation of the AI have been standardized: trunked mode operation (TMO) and DMO. A standardized Peripheral Equipment Interface (PEI) is also available. The PEI allows splitting the TETRA terminal in two separate devices: the terminal equipment (TE) and the mobile termination (MT). The equipment may be a PC or any other computing device, while the MT acts like a modem.

TETRA has been proven a suitable technology for large mission-critical networks. The ETSI TETRA standard has been deployed in over 120 countries worldwide, and, even though TETRA has been commonly adopted by many types of professional users, the emergency service sector remains the largest group of users using this standard. Indeed, most EU member states have rolled out national TETRA networks for PPDR (e.g. Belgium, Denmark, Germany, Finland, Sweden, etc.).

With regard to TEDS, equipment supporting the new data features entered the market in 2008–2009. However, the adoption of TEDS is still quite limited (TEDS is currently being deployed in some Northern countries). TETRA networks are also being deployed in North America, now that the Federal Communications Commission (FCC) allows the technology to be used there, but not for PS where the P25 standard is used.

1.4.3.2 TETRAPOL

TETRAPOL is another relevant NB technology in the European PPDR sector. TETRAPOL is a proprietary technology that was initially developed by a French company named MATRA in the 80s and gained a first-mover advantage over TETRA. Nowadays, the development of the technology remains in the hands of the French industrial group Airbus Defence and Space (which integrated the formerly known as EADS/Cassidian), which is the single provider worldwide. For the promotion of the technology, the TETRAPOL Forum was created, through which the specifications of the technology are available (in the form of Publicly Available Specifications (PAS)) to manufacturers who want to develop compatible products or solutions for TETRAPOL networks.

TETRAPOL is based on FDMA with 12.5-kHz carrier spacing, supporting one voice channel per carrier. This configuration gives some advantages in terms of coverage compared to TETRA systems, but at the expense of lower spectral efficiency. Like TETRA, TETRAPOL supports many features and functionalities for voice-centric services (multisite open channels, talk groups, direct mode, etc.). Fallback modes as well as DMO repeaters and direct mode to trunked mode (DMO–TMO) gateway repeaters are also supported in TETRAPOL systems. Another relevant characteristic of TETRAPOL is simulcast support (simultaneous transmission of the same information from multiple cell sites over the same RF channel). This allows systems to be rolled out even when few channels are available, as it is likely to be the case in most big cities. Nevertheless, data transmission capabilities of TETRAPOL are more limited than in TETRA.

TETRAPOL also includes the specification of some APIs, which enable third-party application developers to create complementary voice and data applications for TETRAPOL users. Applications developed using these APIs include command and control room solutions, AVL

applications based on GPS location information, user management, network supervision and management applications.

Large PS networks based on TETRAPOL are nowadays deployed in France, Spain, Slovakia and Switzerland, along with smaller networks in the Czech Republic and Romania. While the largest market of the TETRAPOL technology has been Europe, the technology has also been deployed for nationwide or wide area PPDR in a few countries within Latin America, Africa and Asia, being one of the largest deployments the Mexican 'Red Iris' network with over 1 million terminals.

1.4.3.3 DMR

DMR is a European standard also developed under ETSI. The DMR standard, first ratified in 2005, was developed with the objective to create an affordable digital system with lower complexity than TETRA but able to satisfy the needs of many PMR users and easing the direct replacement of legacy analogue PMR [21]. The promotion and certification of the technology is conducted by the DMR Association.

The standard is designed to operate within the existing 12.5-kHz channel spacing in a wide range of frequency bands (i.e. from 66 to 960 MHz). DMR provides voice, data and other supplementary services. DMR comprises three substandards:

1. DMR Tier I is mainly designed for licence-free use in the 446-MHz band. Tier I provides for consumer applications and low-power commercial applications, using a maximum of 0.5-W RF power. With a limited number of channels and no use of repeaters and no use of telephone interconnects and fixed/integrated antennas, Tier I DMR devices are suited for personal use, recreation, small retail and other settings that do not require wide area coverage or advanced features. DMR Tier I is based on a FDMA AI.
2. DMR Tier II covers licenced conventional radio systems, mobiles and hand portables operating in PMR frequency bands from 66 to 960 MHz. This standard is targeted at users who need spectral efficiency, advanced voice features and integrated IP data services in licensed bands for high-power communications. It specifies two-slot TDMA in 12.5-kHz channels. Accordingly, DMR II provides the equivalent of two 6.25-kHz voice or data paths in a 12.5-kHz channel.
3. DMR Tier III covers trunking operation in frequency bands 66–960 MHz. Tier III supports voice and short messaging handling with built-in character status messaging and short messaging. It also supports PD service in a variety of formats, including support for IPv4 and IPv6. The Tier III standard is also based on a two-slot TDMA radio interface in 12.5-kHz channels.

DMR manufacturers have made a significant effort to guarantee that a certain number of DMR radio features are compatible across different manufacturers through interoperability tests. Some manufacturers have been certified as having that basic number of DMR features interoperable between vendors, and more manufacturers will pursue and obtain similar certifications in the future.

DRM equipment is sold today in all regions of the world, being actual applications mainly focused on the Tier II and III licensed categories. According to the DMR Association, while

the DMR standard is being used in the PS market, the largest vertical market for this technology is actually the industrial sector.

1.4.3.4 Project 25

Project 25 (P25) is the standard for the design and manufacture of interoperable digital two-way wireless communications developed in North America under the auspices of the Telecommunications Industry Association (TIA). A P25 Steering Committee, collaborated by the Association of Public-Safety Communications Officials (APCO) International and other US national associations and federal agencies, was formed in 1989 to provide a set of industry standards for a PMR digital technology intended to replace the legacy analogue systems. The published P25 standards suite is administered by the TIA Mobile and Personal Private Radio Standards Committee (TIA/TR-8). Similar to TETRA TCCA and TETRAPOL Forum, the Project 25 Technology Interest Group (PTIG) was created to promote the success of Project 25 and educate interested parties on the benefits that the standard offers.

The initial specifications of P25 (P25 Phase 1) focused on the Common Air Interface (CAI) and vocoder as its baseline. Phase 1 included the specifications for 12.5-kHz FDMA equipment and systems that could interoperate with multiple vendors' radios in conventional or trunked mode, as well as legacy analogue FM radio systems. The CAI standard was completed in 1995. Since then, additional Phase 1 standards have been developed to address trunking; security services, including encryption and OTAR; network management and telephone interfaces; and the data network interface. Additionally, there have been ongoing maintenance revisions and updates to the existing standards.

P25 Phase 2 was designed to satisfy PS's need to transition to a 6.25-kHz or equivalent occupied channel bandwidth and maintain backward compatibility to Phase 1 technology, allowing for graceful migration towards greater spectrum efficiency. Although the need was identified for standards to address additional interfaces and testing procedures, the primary focus for the Phase 2 suite of standards was defined by a two-slot TDMA approach to spectrum efficiency as opposed to a 6.25-kHz FDMA technology. The Phase 2 suite of standards addressing TDMA trunking technology was completed and published in 2012, but the standards allowing initial product development were published back in 2010.

P25 supports both voice and data digital communications with data rates of 9.6 kb/s. A variety of system configurations are allowed, including direct mode, repeated, single site, multisite, voting, multicast and simulcast operation. Both conventional and trunked operations are supported in local and wide area configurations. P25 also offers high-power operation allowing large geographic areas to be covered with fewer sites than other technologies, making P25 technology an economical and efficient choice. The P25 standard itself is frequency agnostic. P25 equipment is available from numerous suppliers in VHF, UHF and 700-, 800- and 900-MHz frequency bands to meet the diverse frequency requirements of agencies around the world. The standard enables multiple frequency bands to be supported on one system. P25 supports secure communication through the use of federal government endorsed 256-bit key AES encryption, key management and equipment authentication.

In addition to the CAI, the P25 standard suite also enables interoperability for wire line interfaces. In this regard, a significant number of standards documents addressing the P25 Inter-RF Subsystem Interface (ISSI) have been developed and published. The standards for

the Conventional Fixed Station Interface (CFSI) and Console Subsystem Interface (CSSI) have also been completed and deployed. Additionally, standards have been developed and published to address a number of interfaces relevant to security services, to include the Inter-Key Management Facility Interface (IKI). Interoperability testing is addressed through the P25 Compliance Assessment Program (CAP), a voluntary program that allows suppliers of P25 equipment to demonstrate that their respective products are compliant with P25 baseline requirements reflected in the suite of standards.

In the United States, P25 is widely adopted at different jurisdictional levels, from local to federal agencies, and has the support of the US Department of Homeland Security (DHS) that requires the implementation of this standard in the PMR equipment used for emergency communications [22]. P25 is also deployed in many other countries in the Americas, and there are some deployments throughout other regions in the world [31].

1.4.4 Main Limitations with Today's PPDR Communications Systems

Effective interoperable communications can mean the difference between life and death. Unfortunately, inadequate and unreliable communications have compromised emergency response operations for decades. Emergency responders need to share vital information via voice and data across services/disciplines and jurisdictions to successfully respond to day-to-day incidents and large-scale emergencies. Responders often have difficulty communicating when adjacent agencies are assigned to different radio bands, use incompatible proprietary systems and infrastructure and lack adequate standard operating procedures and effective multi-jurisdictional, multidisciplinary governance structures. This diversity is reflected in the different types of equipment and use of radio-frequency spectrum bands by PPDR organizations. Operational procedures are also quite different, which is a major problem for border security organizations.

The issues and problems identified with today's PPDR communications system can be well explained through the analysis of PPDR operations in a major incident.

PPDR scenarios have been described in a number of projects and initiatives (e.g. [5, 12, 23, 24]). The one described here was developed within the European research project HELP [25]. The scenario creates a hypothetical location, incident circumstances and response. However, the resources available at such a location are realistic as are the varied PPDR communications means available. For the purposes of emergency services operating methods and requirements, it is reasonable to suggest that, to a certain extent at least, 'an incident is an incident'. This means recognizing that, while there will be issues of scalability and certain incident-specific criteria (such as cross-border communication), it is both unnecessary and unrealistic to manufacture either large numbers of small-scale scenarios or one which is based on a colossal, continent-wide scale. It is far better to create a feasible, realistic incident that contains the relevant operational problems (in effect, a realistic, sequential series of events), from which a scalable technical solution can be developed. This approach is followed in the scenario developed in Project HELP, which concentrates on the early stages of a major incident (see Figure 1.5), rather than the incident as a whole. The scenario describes an incident which could happen in many locations and which, although having relatively small beginnings, expands considerably over a relatively short timeline. The reasoning behind this is that if a solution can be delivered where it matters, when operational resources are limited and operational intelligence

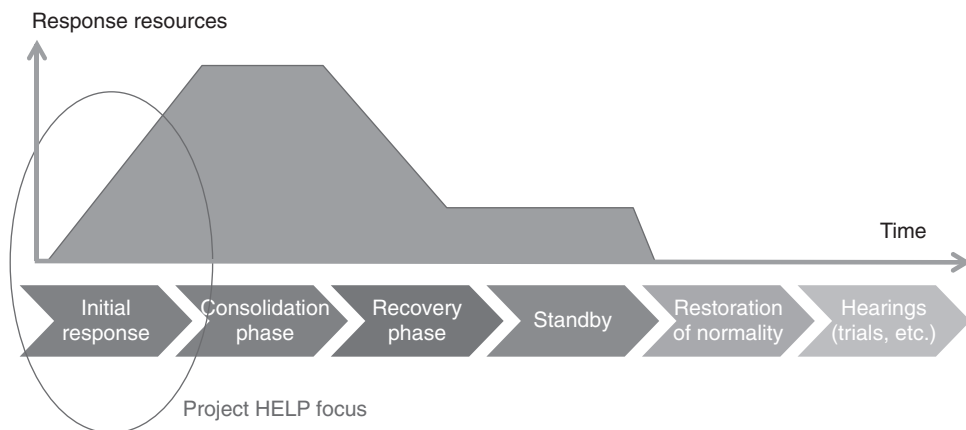


Figure 1.5 Typical stages of a major incident and focus of Project HELP scenario.

regarding the incident is still limited, then that solution can be extended into the longer term as the incident stabilizes and, ultimately, the affected area returns to a state of normality.

1.4.4.1 Description of the Area and Demographics

The location of this incident is on the coast and extending into a largely rural community of some 10km². A coastal town of some 5000 inhabitants is divided by the mouth of a river. Beyond the town lies largely rural agricultural land that is sparsely populated.

The town contains rural police, ambulance and fire stations, all with limited capacity. In all cases, the services provide cover for the town itself and for predefined geographical areas beyond it. In the event of an incident outside this area, it is possible that some of these resources may be called to assist elsewhere. The police service provides a 24-h presence with two patrol vehicles and usually no more than four officers available at any one time. The fire and rescue service for the town is ‘retained’ (part-time), consisting of crews who are in other forms of full-time work and are called when required for fire and rescue duties by Short Message Service (SMS). The ambulance service for the area has one rapid-response vehicle. This is staffed by a skilled medical paramedic who can use specialist equipment such as defibrillators and administer controlled drugs. The vehicle is equipped accordingly. The safety of the people using the adjacent coastal area is primarily the responsibility of the local maritime rescue service. This area is serviced by an inshore patrol boat using a crew of three. The crew is provided using a ‘retained’ service and call-out system similar to (but discrete from) that of the fire and rescue service. There is a railway station in the town directly linked to the national rail network. This is policed by the national transport police. The area headquarters for each of the three principal services lie outside the scenario area. There is no hospital in the area, although there is a doctors’ surgery in the town. It provides general medical services during office hours and has no emergency response structure.

A sketch map of the area and the emergency service resources available is shown in Figure 1.6. The map shows the area geography; the location of main road and rail systems; the location of police, ambulance and fire stations; and the key installations.

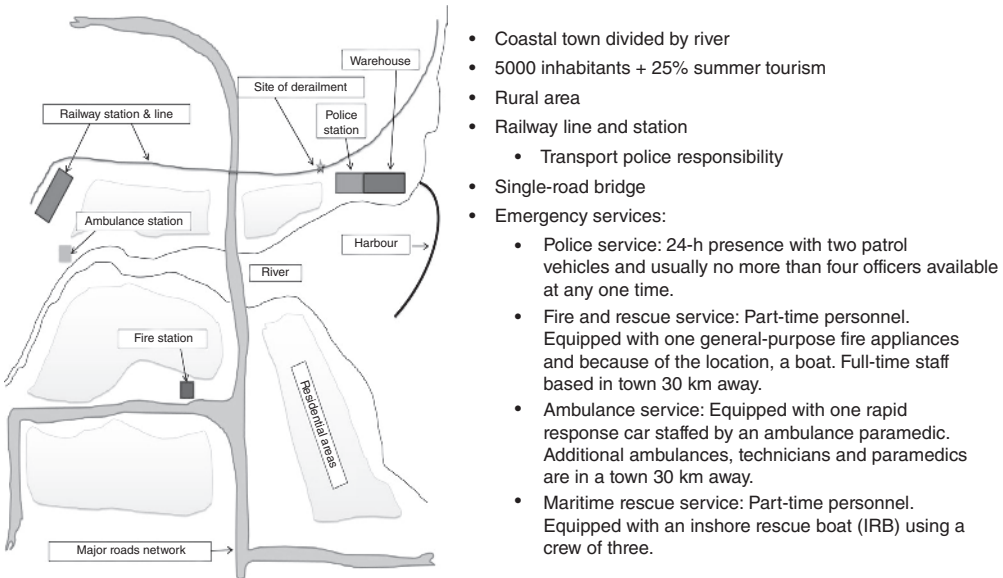


Figure 1.6 Scenario map of the area and the emergency service resources available.

1.4.4.2 Description of the Available Communications Means

The police and ambulance services each use their own area of a common, dedicated communications system for voice and data transmission (herein referred to as the public safety network (PSN)). In addition, they may use the commercial cellular telephone network in the area. A base station of the dedicated PSN is located on the roof of the police station. This base station has a diesel-powered generator as backup in the event of mains power failure. As the area is mainly rural in character, the PSN has limited capacity in comparison to an urban area.

The fire and rescue service uses a mixture of analogue and digital radio equipment on VHF frequencies. The nearest VHF base station used by the fire service is located on top of a mountain some 50 km distant.

The nearest VHF base station used by the transport police is located on the local railway station. This organization uses an autonomous VHF analogue radio system on a different frequency to that used by the fire and rescue service.

The local police, ambulance and fire facilities are connected to their control centres (which are not necessarily co-terminus with their headquarters and are outside the incident area) by the PSN (police and ambulance only), VHF analogue/digital system (fire services), internal secure computer networks (usually hardwired or microwave), landline telephone and fax.

Two public mobile networks (PMNs) are assumed to cover the area. Commercial telecom providers deliver voice and data communications (e.g. Internet access) over these infrastructures. BB access is provided although capacity and coverage are reduced in comparison to nearby urban areas.

The following communications equipment is available for local PS services:

- PSN handheld terminals for police and ambulance services that also support direct or back-to-back mode, in areas where the network coverage is poor or non-existent
- Dedicated VHF TE for the fire and rescue service and transport police
- COTS systems, used to supplement the above, particularly for data exchange (e.g. RIM Blackberry terminals)
- Commercial cellular telephony, a combination of terminals owned by the organization or owned privately by individuals within organizations

In addition, police patrol and ambulance vehicles are usually equipped with higher-power (e.g. 10W) vehicle-mounted PSN terminals. In some instances, these vehicles may be equipped with gateway functionalities (e.g. handheld terminals can access the services of the PSN through this vehicle-mounted equipment). Moreover, out-of-area emergency units that arrive later to assist may also bring communications equipment as described previously as well as more specialized equipment for emergency management such as fast deployable network equipment (e.g. to establish an incident area network for video, data and sensor communications) and satellite communications equipment.

Table 1.6 summarizes the above-mentioned wireless communications means.

Table 1.6 Wireless communications means available for the PPDR services to assist in the emergency response.

Type of communications means	Available wireless communications means	Description
Permanent communications networks	Public safety network (PSN)	Dedicated, digital trunked communications system for voice and data transmission. The police and ambulance services regularly use this network for their internal communications
	VHF base stations for analogue/digital public safety communications	Mixture of analogue and digital radio equipment on VHF frequencies regularly used by fire and rescue services and transport police
	Public mobile networks (PMNs)	Two mobile cellular networks in the area host a number of commercial telecom providers. These provide voice and data communications. Broadband access is provided although capacity and coverage are reduced in comparison to nearby urban areas
Handheld, portable or vehicle-mounted communications equipment available for local PPDR services or brought into the incident area	PSN and VHF handheld terminals	This is the equipment regularly available for local PPDR services and most out-of-area emergency support units
	Commercial cellular telephony and COTS systems for data exchange	
	Vehicle-mounted PSN terminals and gateways	Specialized equipment for emergency management that can be brought by out-of-area emergency support units
	Fast deployable network equipment to establish incident area networks	
	Satellite communications equipment	

1.4.4.3 Brief Description of the Incident and Impact on the Communications Means

At some stage during normal working hours on a weekday, a train carrying liquid petroleum gas (LPG) is derailed close to the town. Two of the wagons are ruptured allowing LPG to leak out. This gathers around nearby houses. After some minutes, an explosion occurs, followed by a widespread fire. This fire attacks a building that contains paints and thinning chemicals in large quantities. The onshore wind will cause toxic fumes from the fire to move across a largely residential area. There are people trapped inside the building: staff in the basement and staff and customers on the ground floor. One of the adjacent buildings involved is home to local police station and has on its roof one of the local PSN base stations.

Initial calls are made to the emergency services from members of the public over the PMNs and from nearby premises over the landline telephone system. Local 'retained' fire services are called out via SMS, and the area police and ambulance services are tasked to attend. Information on the status and extent of the incident is being passed by the first resource at the scene via radio to their control centre and from there by telephone and data transfer to the other control centres, from where it is relayed back out to the respective resources at or attending the scene. The local retained fire service arrives on the scene. They also request out-of-area support from their own service: the fire is beyond their capacity to bring under control. Dense smoke and fumes are rising from the fire and drifting inland. As the local ambulance service arrives at scene, they also request additional support via their own communications channels as there are an unknown number of casualties inside the building, compounded by the fact that the fire is spreading and putting further lives at risk. Other local resources are mobilized to assist. For example, maritime rescue units are commanded to keep boats out of the harbour and provide information and assistance to those vessels out in the bay area.

This incident requires not only the existing local emergency services to respond and collaborate but also requires the attendance of additional resources from outside the area as a matter of urgency. Some of the additional teams are not authorized users on the PSN and brought some equipment that is not interoperable with the local communications system. The emergency service support personnel and equipment are moving into the area to be directed by operational-level commanders. Tactical-level command posts are established as close to the affected area as it is safe to do. Communications links between the different command levels must be established and maintained. These mobile control centres should have direct voice/data communications links back to their respective control centres.

Resources entering the building to tackle the fire and/or rescue people inside will require the use of direct mode (back-to-back) communication as radio coverage from base stations may not stretch to the interior of buildings and will certainly not deliver to subterranean levels. Moreover, the PSN is stretched to capacity simply by the attendance and requirements of the local emergency crews. When support emergency resources start to arrive from outside the area, the network capacity is exceeded. From the outset, some communications will take place across the mobile cellular network, and this will increase as it becomes more difficult to get through on the PSN. Things get much worse when the PSN base station on the roof of the police station building is destroyed by the fire.

1.4.4.4 Focus Areas

The full description of the Project HELP operational scenario [26] included a timeline of events, where the evolution of the incident raised the need for many different communications among many different actors and where a number of limitations in terms of communications needs became evident during the incident. An excerpt of the timeline of events is reproduced in Table 1.7. As shown in the table, for each event, the required communications activities are described along with the limitations faced in the considered scenario. As an illustrative example, Event 12 shows that the arrival of PPDR specialist teams and additional personnel to the incident area turns into network capacity limitations at scene that would put some limits on the utilization of advanced equipment for emergency response.

The overall timeline of events spanned over a time duration of 2 h. The limitations arisen were captured under the concept of ‘focus area’, which represents the key stress points (i.e. those where the PS services and/or technical systems would be under maximum strain) within the operational scenario. As a result of the analysis conducted in Project HELP, three focus areas were identified:

1. Providing enough communication capacity for PPDR units in the incident area. The high concentration of first responders in the incident area makes the PSN to be over capacity. If arriving out-of-area emergency support units do not bring additional on-board capacity (e.g. fast deployable base stations), then they will add significantly to the load already being placed on the networks. In addition, the capacity/coverage provided by infrastructure networks may not match the spatial/temporal capacity/coverage needs across the affected area. In turn, the limited available capacity and/or the lack of BB connectivity at scene prevent the utilization of advanced equipment and applications for emergency response that might be used by attending specialist emergency support units. Even in the case that priority access for PPDR users to PMNs is supported, organizational complications in managing the priority service frequently render it virtually useless.
2. Facilitating communications interoperability between PPDR units (local, support and command). In the considered scenario, supervisors at the scene are unable to communicate/coordinate between each other across emergency services due to interoperability issues between the dedicated PPDR systems (e.g. PSN and VHF systems). First responders arriving from other areas, even those equipped with compatible technology, are unable to use the existing PSN infrastructure. There is no capability to set up inter-agency channels when users are spread over several networks. Furthermore, there is a lack of coordination in the configuration of radio equipment brought to the incident area by different agencies.
3. Coping with sudden network base station failure during the incident response. It is highly probable that in a scenario like this, the PSN base station would have failed before tactical-level command units are properly established. Unless these units are able to move onto other networks, there is a very real risk that police and ambulance tactical-level control centres would be unable to carry out a major part of their role for some considerable time. Nevertheless, the usage of commercial network as alternative communications means when PSN base station fails is up to the emergency responders and not an automatic procedure at all. Relying only on back-to-back communications after PSN base station failure is likely to turn on some on-scene resources unable to communicate with their respective tactical-level control centres due to the limited transmission range of individual TE.

Table 1.7 Excerpt of the timeline of events in the Project HELP scenario.

Event number Time: (h:min)	Event description	Communications activity	Current limitations
1 0:00	Train carrying LPG derails LPG leaks out and disperses around nearby houses Mobile and fixed telephone calls reporting incident received by emergency control centres	Public telephone (fixed/mobile) calls directed to emergency services as requested by callers Mobile networks soon under strain as a result of calls reporting the incident, people trying to transmit pictures/video, etc. Note that many of these transmissions will not be to emergency services but to friends/family and the media	None to PPDR at this stage
2 +0:03	Local police and ambulance respond to calls from respective control centres and attend scene	Landline and cellular calls to emergency services continue Control centre calls to local police and ambulance resources over the PSN Incident detail transmitted to local fire station from control centres for staff information on arrival Fire call-out SMS system activated	Messages being received by disparate agencies/locations. Coordination and collation of information and response Public calls routed based on their assessment – not necessarily correctly
...			
6 +0:12	Leaking LPG explodes causing massive fire Fire attacks the building containing paint and chemicals. People inside. Building structure is physically linked to local police station with PSN base station on roof	Reported to control centres by resources at scene Significant increase in mobile calls from concerned members of the public and spectators Possibility that local TV or other media may be in the area and making demands on mobile network capacity	This mobile activity may well take mobile networks towards maximum capacity level Significant threat now to PSN due to proximity of fire to the base station
...			
12 +1:10	PPDR specialist support units are moving into the area. Additional personnel to assist at the scene(s) are trying to get there. On arrival will be using existing communications networks	Increasing demand on mobile phone networks and PSN	Issues of congestion arising on the mobile networks due to significant use of the system by people in the area Communications equipment brought by support teams is not interoperable with local systems Some of the arriving support staff are not authorized subscribers on the existing PSN Available capacity at scene would put some limits on the utilization of advanced equipment for emergency response that might be used by attending specialized units
...			

1.4.4.5 Major Limitations

Based on the analysis of the previous scenario, the following major limitations associated with PPDR systems and arrangements used nowadays in emergency and DR scenarios can be drawn:

- **Lack of network capacity in emergency scenarios.** While the PPDR network operators have optimized the use of their communication systems in their day-to-day service, the situation changes dramatically when an emergency causes additional stress for the system (and the operators). Emergency scenarios usually lead to exceptionally high traffic loads, which a single wireless network may not be able to support. This situation can be worsened in scenarios with limited radio coverage (e.g. a traffic crash in a tunnel) or when parts of the communications infrastructure are damaged in the incident area.
- **Lack of interoperability.** The diversity of technologies used by PPDR organizations often inhibits cooperation between different agencies. Moreover, even when using the same technology, the networks cannot interoperate and the constraints on the security level constitute an additional barrier. As a result, first responders are frequently required to manage several disparate and often incompatible radiocommunication systems.
- **Lack of support for BB data rates in terms of both functionality and capacity.** The evolution of PPDR operations has created the need for applications where large amounts of data are exchanged between first responders or between the tactical-level front-line responders and multilevels of a hierarchical command structure. Data-intensive multimedia applications have a great potential to improve the efficiency of disaster recovery operations (e.g. real-time access to critical data such as high-resolution maps or floor plans; on-field live video transmission from helmet cameras to a central unit, telemedicine, etc.).

1.5 Regulatory and Standardization Framework

Governments and public administrations in each country are the ultimate responsible bodies for establishing the legal and regulatory provisions as well as determining the technical framework (e.g. frequencies, standards) for the delivery of PPDR communications, insofar as the PPDR sector is intimately connected to the public sector of society, either directly as part of the governmental structure or as a function which is outsourced under strict rules. Regulatory, organizational, operational and technical elements can vary substantially from country to country, since the PPDR structures are necessarily tuned to the country's specifics. However, national provisions shall be necessarily conjugated with international regulation and harmonization measures. In turn, international regulation and technical harmonization for PPDR communications is central to facilitate a successful cooperation in PPDR operations in international responses to disasters and cross-border cooperation among many nations. This requires the establishment of international legal instruments to provide guidance in these cases and make national legislations to be conformant with the applicable international law [27], while safeguarding any specific national interests. Indeed, complementing or superseding national regulations for some emergency communications matters, regional regulations are already in place in some parts of the world, like in Europe and the United States/Canada. Together with regulatory provisions, the adoption of global standards for PPDR communications systems and the use of harmonized frequencies are also central

aspects towards more efficient and effective PPDR communications at a regional and even global scale. Besides the benefits associated with being able to cooperatively utilize the PPDR resources of different countries in an effective manner, harmonization is also crucial for the ordinary citizens. Citizens are increasingly mobile; they travel for business, for holidays, etc. In order to provide an optimum level of security and accessibility to these citizens in emergency situations, the emergency telecommunications services (ETS) also need harmonization. In this context, a central role in the regulation and standardization of PPDR communications at international level is played by ITU, which is the United Nations' specialized agency in the field of telecommunications and information and communications technologies (ICTs). ITU provides key definitions of PPDR communications concepts and solutions, including standards and spectrum harmonization.

A comprehensive collection of regulatory aspects and existing known emergency communication standards worldwide has been released by the Global Standards Collaboration (GSC) [31]. The GSC is an international initiative to enhance cooperation between standards development organizations (SDOs) from different regions of the world in order to facilitate exchange of information on standards development, build synergies and reduce duplication. The present membership is represented by the following organizations: Association of Radio Industries and Business (ARIB, Japan), Alliance for Telecommunications Industry (ATIS, United States), China Communications Standards Association (CCSA, China), ETSI (Europe), ICT Standards Advisory Council of Canada (ISACC, Canada), ITU (International), Telecommunication Technology Committee (TTC, Japan), TIA (United States) and Telecommunications Technology Association (TTA, Korea). Within the GSC, a task force on emergency communications was established to further encourage cooperation and the sharing of information on standardization activities relating to communications in emergency situations. The addressed work covers not only PPDR communications but also standardization in the areas of communications from individuals/organizations to authorities, communications from authorities to individuals/organizations and communications among affected individuals/organizations. The aim of the document elaborated by the GSC is to identify commonalities, gaps and possible overlaps of emergency communications-related standards in all regions. The document is concluded by looking to the future and examining what may exist tomorrow as well as making proposals to the GSC in order to ensure enhanced harmonization and cooperation.

With all the above, this section first provides an overview of the main activities at the global level conducted within ITU on emergency communications regulation and standardization. Following this, a description of some leading regulatory initiatives and standardization work related to PPDR communications in a number of countries across the North and Latin America, Asia and Pacific and European regions is provided. Complementing these descriptions, Chapter 3 provides further details on a number of relevant initiatives that are currently shaping the way forwards towards the actual delivery of PPDR BB communications based on the LTE technology ecosystem. Moreover, standardization activities concerning the LTE technology and related mission-critical BB applications are covered in more details in Chapter 4, and further details on spectrum regulation for PPDR communications are covered in Chapter 6.

1.5.1 ITU Work on Emergency Communications

The ITU was established last century as an impartial, international organization within which governments and the private sector can work together to coordinate the operation

of telecommunications networks and services and advance the development of communications technology. Article 1, Section 2 of the ITU Constitution provides that ITU shall '*promote the adoption of measures for ensuring the safety of life through the cooperation of telecommunication services*'. This mandate has been further enhanced through resolutions and recommendations adopted by past and recent World Telecommunication Development Conferences (WTDC) and World Radiocommunication Conferences (WRC), and ITU's Plenipotentiary Conferences, as well as its active role in activities related to the Tampere Convention. The Tampere Convention calls on states to facilitate the provision of prompt telecommunications assistance to mitigate the impact of a disaster and covers both the installation and operation of reliable, flexible telecommunications services [32].

ITU is organized in three sectors: Telecommunication Development (ITU-D), Standardization (ITU-T) and Radiocommunication (ITU-R). The activities concerning different aspects of emergency communications are addressed within the three sectors [27].

The core mission of the Telecommunication Development (ITU-D) Sector is to foster international cooperation and solidarity in the delivery of technical assistance and in the creation, development and improvement of telecommunications/ICT equipment and networks in developing countries. ITU-D engagement in development support for disaster communications includes partnership for direct assistance to the disaster-prone countries with technical assistance and support for operational costs, deployment of donated satellite phones in disaster-stricken areas and projects on rehabilitation and reconstruction of telecommunications infrastructure in earthquake/tsunami-hit areas. ITU-D works in close cooperation with the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) and is a member of the Working Group on Emergency Telecommunications (WGET), an open forum including all United Nations' entities and numerous international and national and governmental organizations and NGOs involved in disaster response as well as experts from the private sector and academia. The role of the ITU-D under the Tampere Convention and other related instruments is explained in Ref. [27]. Currently, 46 countries have ratified the Tampere Convention on the Provision of Telecommunication Resources for Disaster Mitigation and Relief Operations. Further information on the role of ITU-D in emergency communications can be found at the ITU-D website [28].

Through its work on standardization, the ITU Telecommunication Standardization (ITU-T) Sector develops technical standards that facilitate the use of public telecommunications services and systems for communications during emergency, DR and mitigation operations. Although ITU-T is not involved in emergency and DR operations *per se*, it develops recommendations that are fundamental to the implementation of interoperable systems and telecommunications facilities that will allow relief workers to smoothly deploy telecom equipment and services. The World Telecommunication Standardization Assembly (WTSA), which meets every 4 years, establishes the topics for study by the ITU-T study groups. In this context, ITU-T main activities are related to the provision of an ETS that is defined as a national service providing priority telecommunications to authorized users in times of disaster and emergencies. A number of recommendations have been developed for call priority schemes that ensure that relief workers can get communications lines when they need to. Supplement 62 to the ITU-T Q-series Recommendations [34] provides a convenient reference to assist ITU-T study groups and other national and international SDOs as they develop recommendations and standards for ETS. It identifies published ETS-related recommendations and standards

as well as those currently in work programmes. Further information of the role of ITU-T in emergency communications can be found at the ITU-T website [29].

The ITU-R Sector is actually the sector more directly involved in PPDR radiocommunications regulation and standardization. The role of the ITU-R is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services. The regulatory and policy functions of ITU-R are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by study groups. WRC are regularly held every 4–5 years, and the decisions adopted are incorporated in the Radio Regulations (RR) treaty [33].

The subject of frequency bands for PPDR communications was an important item on the agenda of the WRC held in 2003 (WRC-2003). Previously, WRC-2000 approved agenda item 1.3 for WRC-2003 to consider identification of globally/regionally harmonized bands, to the extent practicable, for the implementation of future advanced solutions to meet the needs of PP agencies, including those dealing with emergency situations and DR, and to make regulatory provisions, as necessary, taking into account Resolutions 644 (Rev. WRC-2000) and 645 (WRC-2000). These resolutions requested ITU-R study groups to pursue studies on the identification of suitable frequency bands, as well as on facilitating cross-border circulation of equipment intended for use in emergency and DR situations – the latter point reinforced by the Tampere Convention on the Provision of Telecommunication Resources for Disaster Mitigation and Relief Operations. The focus in 2003 was to identify bands for mission-critical voice and data for PPDR agencies. Resolution 646 was approved by WRC-2003 including the identified regional harmonized frequency bands. Indeed, report ITU-R M.2033 [1] was delivered in preparation for WRC-03 agenda item 1.3, which defined the PPDR objectives and requirements for the implementation of future advanced solutions to satisfy the operational needs of PPDR organizations around the year 2010. Specifically, ITU-R M.2033 identified objectives, applications, requirements, a methodology for spectrum calculations, spectrum requirements and solutions for interoperability. From 2003 till date, ITU has been continuously working on preparing reports and recommendations on PPDR, but the last adopted PPDR resolution is still Resolution 646. In the last WRC-2012, to account for the new PPDR scenarios offered by the evolution of BB technologies, it was agreed to review and revise Resolution 646 for BB PPDR under agenda item 1.3 in the forthcoming WRC-2015. In particular, Resolution 648 invited ITU-R to study technical and operational issues relating to BB PPDR and its further development and to develop recommendations, as required, on technical requirements for PPDR services and applications, the evolution of BB PPDR through advances in technology and the needs of developing countries. Further details on spectrum regulation and frequency arrangements for PPDR are provided in Chapter 6.

With respect to PPDR communications standards, ITU-R Recommendation M.2009 identifies a set of radio interface standards applicable for PPDR operations. These standards are not developed by ITU but based on common specifications issued by different SDOs. The recommendation is intended to be used by regulators, manufacturers and PPDR operators to determine the most suitable standards for their needs. However, as explicitly noted in the Recommendation, the inclusion of ITU-R M.2009 standards does not preclude the use of other standards, if so considered by the administration that is the ultimate responsible for determining which technologies to deploy for PPDR operations.

The NB standards (and respective responsible SDOs) for PPDR operations listed in ITU-R M.2009 are TETRA, P25 and DMR. In addition, the following BB technologies are also listed in ITU-R M.2009:

- IMT-2000 CDMA-MC technology, developed within 3rd Generation Partnership Project 2 (3GPP2). This is the technology used in commercial CDMA2000 networks.
- IMT-2000 CDMA-DS, specifically UTRA FDD, developed within 3rd Generation Partnership Project (3GPP). This is the technology used in commercial UMTS systems deployed over paired bands, which are the vast majority of UMTS systems.
- OFDMA TDD WMAN, developed within the IEEE 802.16. This is the technology more commonly known as WiMAX.
- TDMA-SC, developed within 3GPP. This is the technology behind the EDGE systems evolved from the 2G GSM radio interfaces.
- IMT-2000 CDMA TDD, specifically UTRA TDD, technology is developed within 3GPP. This is the technology developed for UMTS systems to be deployed in unpaired bands.
- E-UTRA (LTE) technology, developed within 3GPP.

Further information of the role of ITU-R in emergency communications can be found at the ITU-R website [30].

1.5.2 North and Latin America Regions

In the United States, the vast majority of PPDR networks currently utilized are NB systems that are governed by Part 90 of the FCC's rules. Part 90 consists of various services utilizing regularly interacting groups of base, mobile, portable and associated control and relay stations for private (non-profit) radiocommunications by eligible users. These systems use Project 25 (P25) suite of standards (briefly described in Section 1.4.3.4). Standardization activities related to P25 and other aspects of PPDR communications in the United States are addressed under the auspices of the TIA.

In February 2012, with the passage of the Middle Class Tax Relief and Job Creation Act, regulatory and financial provisions were established for the build out of a dedicated National Public Safety Broadband Network (NPSBN) in the United States. The law's governing framework for the deployment and operation of this network, which is to be based on a single, national network architecture, is the new First Responder Network Authority (or FirstNet), an independent authority within the National Telecommunications and Information Administration (NTIA). FirstNet counts with a spectrum allocation of 10+10 MHz in the 700-MHz band and is charged with taking 'all actions necessary' to build, deploy and operate the network, in consultation with PS entities at all jurisdictional levels and other key stakeholders.

In 2009, the National Public Safety Telecommunications Council (NPSTC), organization that provides a collective voice on communications issues for PS first responders in the United States, endorsed LTE as the favoured technology standard most suited to the development of this anticipated nationwide interoperable BB network [35]. A partnership between the NPSTC and the APCO International, which is the world's largest organization of PS communications professionals, was established in 2013 to move forward on technical standards issues related to PS BB communications. Another leading effort from the United States towards the adoption

and improvement of LTE standard capabilities for PPDR use is the Public Safety Communications Research (PSCR) program, a joint effort between the National Institute of Standards and Technologies (NIST) and NTIA, which coordinates interoperability testing and standards development for the nationwide PS LTE network.

In Canada, NB PPDR networks are using several LMR standards including P25 and ETSI DMR standards. Currently, the only bands where a given standard is mandated for PS spectrum in Canada is in the bands 769–775 and 799–805 MHz, where the P25 standard was selected for operation on the interoperability channels. Industry Canada (IC), a department of the Government of Canada, has also mandated that all mobiles and portables that provide voice services must be capable of operating on the interoperability channels.

The PPDR community in Canada is also engaged in the allocation of dedicated spectrum in the 700-MHz band to deploy a BB network for PPDR. The Communications Interoperability Strategy for Canada (CISC), which is the result of the collaborative efforts of leaders representing all levels of government and emergency response services from across Canada, developed an action plan that tasks national emergency management partners to develop the 700-MHz implementation strategy.

The PS community's intent is to harmonize Canadian and US PS BB networks in the 700-MHz spectrum to enable cross-border communications in these bands and establish mechanisms/protocols to avoid interference issues.

In the Latin America region, spectrum for mobile BB PPDR has also been allocated in Brazil in the 700 MHz. Indeed, LTE deployments in very specific areas have been operational by Brazil's army as part of the infrastructure deployed for the soccer's World Cup in 2014. Aligned with the Brazilian approach, the Organization of American States (CITEL) recommended its member states across North, Central and South America that PPDR to consider the 700-MHz band in possible BB PPDR spectrum allocations.

1.5.3 Asia and Pacific Region

In Japan, a NB PMR standard named Integrated Dispatch Radio (IDRA) was specified by the ARIB, which is an external Ministry of Post and Telecommunication (MPT) affiliate and recognized standardization organization. The IDRA system was developed for use mainly in business-oriented mobile communications applications, encompassing emergency services to commercial and industrial organizations. In 2011, the digitization of analogue TV broadcasting service using VHF/UHF bands resulted in the allocation of 32.5 MHz out of the newly available spectrum for BB wireless communications systems for PS. Technical specifications for those BB systems have been also standardized in ARIB.

In South Korea, ETSI TETRA standards have been adopted by TTA, a non-government and non-profit organization for ICT standardization, even though TTA has also produced its own standards for satellite infra on multimedia DR. The government planned to build a mission-critical nationwide PPDR network for sharing among PPDR agencies and designated the National Emergency Management Agency (NEMA) to lead the program. The Korea Communications Commission (KCC) allocated the frequency spectrum of 806–811 and 851–856 MHz for the nationwide PPDR system. NEMA started implementation of the nationwide system based upon NB technology in 2003–2007. Since then, the system has been in operation in major cities and major express ways. The program was planned for the second phase of PPDR system, which includes BB service.

In China, GoTa based on CDMA and GT800 based on GSM are the popular digital trunking mobile communications systems. These systems were specified by the CCSA, a non-profit legal organization established by enterprises and institutes in China for carrying out standardization activities in the field of ICT. The Emergency Communication Special Task Group (ST3) in CCSA is responsible to carry out studies on comprehensive, managerial and architectural standards of emergency communication, including policy, network and technology supportive standards. A project called broadband wireless trunking (BWT) was launched in 2011 to support research, development, standardization and applicable evaluation for BB wireless professional communications, with the major applications focused on future PPDR [39]. The BWT project covers the stages of research, standardization and industrialization and is planned to conclude in 2018. In terms of spectrum allocation and technology, China is planning to use TDD LTE for BB PPDR in 1.4GHz. China has also reserved frequencies in the 350–370-MHz range for national security radio networks using TETRA.

In Australia, the Australian Communications and Media Authority (ACMA) is undertaking a number of initiatives to improve spectrum provisions for PPDR in Australia [40]. In particular, ACMA has already made provision for 10MHz of spectrum from the 800-MHz band for the specific purpose of realizing a nationally interoperable cellular 4G data capability, though precise frequencies will be determined at a later stage. ACMA has also created a class licence that provides 50MHz of spectrum in the 4.9-GHz band for PSAs to share Australia-wide. This is intended to provide very high-speed, short-range on-demand capacity to areas of high activity to support a wide range of uses.

Throughout this region, the Asia-Pacific Telecommunity (APT) members support regional harmonization of frequency bands/ranges for future deployment of BB PPDR. It is recognized that different amounts of available spectrum may be used within bands depending on their national circumstances. This will provide flexibility to decide the amount of spectrum and the frequency arrangement that best meets their overall national BB PPDR requirements.

1.5.4 Europe Region

A regional regulation exists in Europe, superseding the national regulations for some topics and therefore requesting coordination between countries. The European Commission (EC), being the executive body of the EU, is responsible for proposing legislation, adopting and implementing measures. The European Council and the European Parliament adopt directives that are implemented by member states of the EU in national laws. In this context, the provision of BB PPDR services has been identified as a policy objective in several EC provisions and reports [36, 37].

A number of European Standards Organizations (ESOs) assist the EC by producing standards and specifications supporting the EU policies. This is mainly achieved through mandates issued from the EC towards the ESOs. Mandates are statements of policy intent where the EC and the member states request the relevant ESOs and their members to develop standards (or a standardization work programme) in coordination with regulatory requirements or other policy initiatives. ETSI is the ESO more directly involved in the standardization of PPDR and emergency communications systems.

Within ETSI, an ETSI SC EMTEL was established. The primary responsibility ETSI SC EMTEL is to solicit and capture the requirements from the stakeholders (including national

authorities responsible for provisioning emergency communications, end users, the EC, communications service providers, network operators, manufacturers and other interested parties) and coordinate the ETSI positions on emergency communications-related issues. ETSI SC EMTEL has produced several documents with requirements for emergency communications between individuals and authorities/organizations, between authorities/organizations, from authorities/organizations to the individuals and among individuals (e.g. [3]). ETSI SC EMTEL maintains a report [38] with the European regulatory texts and orientations applicable for the emergency communications (such as EC directives, commission decisions) and other information or references such as generally applicable regulatory principles.

Other central contributions from ETSI in the field of PPDR communications are the TETRA and DMR standards, both briefly described in previous Section 1.4.3. In addition to these PMR standards, ETSI is also active in emergency calling systems, GMDSS and satellite emergency communications. ETSI is currently working in a number of EC mandates that are linked to PPDR from different angles: Mandate M/284 related to the maintenance of the ETSI harmonized standards in the field of private/professional LMR systems and equipment; Mandate M/493 related to the support of the location-enhanced emergency call service; Mandate M/496 related to the development of standardization regarding space industry; and Mandate M/512 on Reconfigurable Radio System (RRS) related to the development and use of RRS technologies in Europe. Within this latter, there is Objective C that proposes to explore potential areas of synergy among commercial, civil security and military applications in terms of network interfaces and architectures for dynamic use of spectrum resources and of architectures and interfaces for reconfigurable mobile devices for commercial and civil security applications. Also recently, the technical committee (TC), in charge of the TETRA specifications, evolved into the now called TETRA and Critical Communications Evolution (TCCE), which is the TC with responsibility for the provision of user-driven standards for PPDR communications over both BB and NB AIs. Outside ETSI, TC TCCE close cooperates with the TETRA and TCCA, particularly with regard to the development of requirements, use cases and architectures for mission-critical communications standardization.

ETSI TC TCCE and TCCA, together with other relevant organizations such as the NIST from the United States, are working closely with the 3GPP to advance the LTE specifications to better support the needs of critical communications users. Indeed, the 3GPP body unites seven telecommunications SDOs from Asia, Europe and North America (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC), known as ‘Organizational Partners’, together with market representatives and a huge number of companies within the telecom sector across the world to produce the reports and specifications that define the 3GPP technologies. In the context of PPDR communications, group call system enablers and off-network services are among the extensions being added to the LTE specifications. A new 3GPP working group (called SA6 – ‘mission-critical applications’) has been created for the development of applications for specialized communications. These extensions to the LTE standard are described in detail in Chapter 4.

As to radio spectrum matters, another key organization in Europe is the European Conference of Postal and Telecommunications Administrations (CEPT). CEPT, through its Electronic Communications Committee (ECC), brings together 48 countries to develop common policies and regulations in electronic communications and related applications for Europe. CEPT takes also an active role at the international level, preparing common European proposals to represent European interests in the ITU and other international organizations. Concerning PPDR communications, the band 380–385/390–395 MHz is so far the only harmonized band for

permanent NB PPDR systems in Europe, as established in CEPT ECC Decision (08)05. Indeed, the introduction of digital radiocommunication, the TETRA standard and the harmonized frequencies for the national emergency services were developed in response to the requirements of the Schengen Treaty obligations. Nowadays, Frequency Management Project Team 49 (FM PT49) within CEPT ECC is currently working on radio spectrum issues concerning PPDR applications and scenarios, in particular concerning the BB high-speed communications as requested by PPDR organizations. FM PT49 is intended to identify and evaluate suitable bands for European-wide harmonization of spectrum (both below and above 1 GHz), by taking into account cross-border communication issues and PPDR application requirements. A further insight into the CEPT and other European bodies' activities concerning PPDR BB spectrum is addressed in Chapter 6.

In this context, a few European countries have already established the path to follow to eventually offer critical voice and BB data for their PPDR agencies. Notoriously, the UK Home Office has initiated the procurement process that is expected to lead to the replacement of its current NB TETRA system (called Airwave) for a new system, known as the Emergency Services Network (ESN), which will make use of 4G/LTE technology. Further details on this UK program, together with other proposals and initiatives towards the delivery of mobile BB PPDR across Europe (France, Finland, Belgium), are covered under Chapter 3.

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