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| **Radiocommunication Study Groups** |  |
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| Subject: Document 5A/TEMP/142(Rev.2) | **Annex 21 toDocument 5A/306-E** |
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| **English only** |
| Annex 21 to Working Party 5A Chairman’s Report |
| Working document toward a preliminary draft new Report ITU-R M.[B-PPDR]  |
| “Broadband public protection and disaster relief communications” |

1 Scope

2 Introduction

3 References

4 Technical requirements for broadband PPDR services and applications

 4.1 [Functional requirements]

 Editorial note: The content of this section will be taken from the Annex 22 to Doc. [5A/306](http://www.whttp:/www.itu.int/md/R12-WP5A-C-0306/en).

 4.2 Spectrum requirements

 4.3TBD

5 [Aspects of frequency Bands for BPPDR]

6 The evolution of broadband PPDR through advances in technology

 6.1 Current standardized solutions

 6.2 Planned evolutions of the standards

7 The needs of developing countries

8 Abbreviations/Acronyms

Annex 1 Example of a particular PPDR incident scenario using LTE as the representative technology to estimate broadband PPDR spectrum needs

Annex 2 Throughput requirements of broadband PPDR scenarios

Annex 3 Methodology to calculate spectrum requirement

Annex 4 Methodology for the calculation of Broadband PPDR spectrum requirements
within CEPT

Annex 5 Definitions

# 1 Scope

This report addresses the technical and operational issues relating to broadband PPDR and its further development including technical requirements for broadband PPDR services and applications; the evolution of broadband PPDR through advances in technology and the needs of developing countries in accordance with Resolution **648 (WRC-12)**.

# 2 Introduction

In recent decades, demand for global development and enhancement of PPDR applications for public protection requirements has shown a significant increase, in order to enable more efficient and more effective responses to PPDR events including natural and man-made disasters, in addition to responding to routine daily events. At the same time, mobile broadband technologies have advanced rapidly with peak data rates up to 1 Gbit/s in the downlink and 500 Mbit/s in the uplink.

WRC -12 resolved to review the requirements of broadband PPDR technologies and applications, including the need for mobile video and other applications demanding high bit rates by PPDR organizations, and adopted WRC-15 Agenda item 1.3 “ To review and revise Resolution **646** **(Rev.WRC-12)** for broadband public protection and disaster relief (PPDR), in accordance with Resolution **648 (WRC-12)**”

Resolution **648 (WRC-12)** invites ITU‑R to study technical and operational issues relating to broadband PPDR and its further development, and to develop recommendations, as required, on:

– technical requirements for PPDR services and applications;

– the evolution of broadband PPDR through advances in technology;

– the needs of developing countries.

This report addresses those issues.

# 3 References

Editorial note: To look at the reference list in the revised M.2033 and include any references that may be appropriate.

[WDTPDRevision] Report ITU-R M.2033[-1] – Radiocommunication objectives and requirements for public protection and disaster relief, [2003].

NOTE - This document is still in the preliminary stage of being developed and its status will be updated as we go along.

APT, [Working document towards draft new APT] - Report on technical requirements for mission critical broadband PPDR communications.

NOTE - This document is only a working draft and not a final APT-AWG Report. AWG will continue to work on this report and will provide the final report to WP 5A as soon as it is finalised. CEPT ECC Report 199 – User requirements and spectrum needs for future European broadband PPDR systems (Wide Area Networks).

NOTE - A relevant separate ECC Deliverable will at a later stage be provided to depict the decision of CEPT on possible frequency bands/ranges and spectrum needs and requirements.

[Public Safety 700 MHz Broadband Statement of Requirements, v0.6, by the National Public Safety Telecommunications Council (NPSTC), USA, November 8th, 2007.

Public Safety Statement of Requirements (PS SoR) for Communications and Interoperability (C&I), Volume 1, v1.2, by the Department of Homeland Security’s Office for Interoperability and Compatibility, October 2006.

Public Safety Statement of Requirements (PS SoR) for Communications and Interoperability (C&I), Volume 2, v1.0, by the Department of Homeland Security’s Office for Interoperability and Compatibility, August 2006.]

Editor's note: The US to check the validity of the above 3 references for Broadband use.

# 4 Technical requirements for broadband PPDR services and applications

## 4.1 [Functional requirements for BPPDR services and applications]

Editorial note: The content of this section will be taken from Annex 22 to Doc. 5A/306.

## 4.2 Spectrum requirements

In considering, Spectrum Requirements the following need to be assessed:

Editorial note: Bullet points need to be added to reflect the things that need to be assessed when considering spectrum requirements.

Examples of assessments of Broadband PPDR Spectrum Requirements have been done in a number of studies reflecting various environments based on the above elements and considering their unique environments. A short introduction of these examples which are shown in Annex 1 – 4 of this document can be seen in the bullets below:

* Annex 1 – Gives an example provided by Israel which looks at a particular PPDR incident scenario using LTE as the representative technology to estimate Broadband PPDR spectrum needs. Appendix 1 of Annex 1 is an example of the unique applications used by the Israeli PPDR agencies that are needed for their Broadband PPDR systems. Some of these applications have been used in incident scenario shown in Annex 1.
* Annex 2 – Gives an example provided by Motorola that uses a spectrum calculator which allows a user to model up to two incident scenes of small, medium, large or very large emergencies. Appendix 1 of Annex 2 presents some PPDR scenarios using this calculator to estimate the throughput and the bandwidth requirements for these Broadband PPDR scenarios.
* Annex 3 – Gives an example provided by China (People’s Republic of) that looks at the providing spectrum estimates based on the PPDR service traffic (including use of voice, data, image and video services) of Wuhan city (capital of Hubei province) in China. The methodology and calculations are presented in Annex 3. The intent is that it will assist administrations in planning for PPDR services that support a wide range of video applications.
* Annex 4 – Gives an example provided by CEPT of the methodology used in ECC Report 199 for the calculation of Broadband PPDR spectrum requirements within CEPT.

# 5 [Aspects of frequency bands for PPDR

Based upon an ITU-R survey of PPDR communications conducted in the 2012-2015 study period from xx ITU members and international organizations and consequent considerations, the following comments should be noted:

a) there is some uniformity in regard to frequency bands used/identified for broadband PPDR in different countries;

b) while in most countries the bands used for public protection are the same as those used for disaster relief, [but bands may differ between ITU Regions;

c) many administrations have designated or will designate one or more frequency bands for broadband PPDR operations. It should be noted that only particular sub-bands of the frequency ranges or parts thereof listed below are utilised or planned to be utilised in an exclusive manner for PPDR radiocommunications in so called dedicated networks, most of the sub-bands are used or planned to be used on shared basis with commercial operators.

Some administrations in Region 1 are using or plan to use or have identified parts of the frequency bands …

Some administrations in Region 2 are using or plan to use or have identified parts of the frequency bands …

Some administrations in Region 3 are using or plan to use or have identified parts of the frequency bands …

Noting the above, the current preferred reference technology chosen is the latest LTE Release number.]

# 6 The evolution of broadband PPDR through advances in technology

## 6.1 Current standardized solutions

Suitable standards for broadband PPDR are included in Recommendation ITU-R M.2009 “Radio interface standards for use by Public Protection and Disaster Relief operations in some parts of the UHF band in accordance with Resolution **646** **(Rev.WRC-12)**”.

Table 1

PPDR Applications and Examples

| **Application** | **Feature** | **PPDR Example** | **Importance(1)** | **3GPP Technology Based System Capability****(See Note A, B, C)** | **NON IMT Technologies** |
| --- | --- | --- | --- | --- | --- |
| **PP (1)** | **PP (2)** | **DR** |  |  |
| 1. *Narrowband* |   |   |   |   |   |  |  |
| Voice | Person-to-person | Selective calling and addressing | H | H | H | Supported |  |
| One-to-many | Dispatch and group communication | H | H | H | Proposals being considered in 3GPP for this capability in LTE |  |
| Talk-around/direct mode | Groups of portable to portable (mobile-mobile) in close proximity without infrastructure | H | H | H | Proposals being considered in 3GPP for this capability in LTE |  |
|  |
| Push-to-talk | Push-to-talk | H | H | H | Proposals being considered in 3GPP for this capability in LTE |  |
| Instantaneous access to voice path | Push-to-talk and selective priority access | H | H | H | Proposals being considered in 3GPP for this capability in LTE |  |
| Security | Voice encryption/scrambling | H | H | M | Supported |  |
|  |
| Facsimile | Person-to-person | Status, short message | L | L | H | Supported |  |
| One-to-many (broadcasting) | Initial dispatch alert (e.g. address, incident status) | L | L | H | Supported |  |
| Messages | Person-to-person | Status, short message, short e-mail | H | H | H | Supported |  |
| One-to-many (broadcasting) | Initial dispatch alert (e.g. address, incident status) | H | H | H | Supported |  |
| Security | Priority/instantaneous access | Man down alarm button | H | H | H | Supported |  |
| Telemetry | Location status | GPS latitude and longitude information | H | M | H | Supported |  |
| Sensory data | Vehicle telemetry/status | H | H | M | Supported |  |
| EKG (electrocardiograph) in field | H | H | M | Supported |  |
| Database interaction (minimal record size) | Forms based records query | Accessing vehicle license records | H | H | M | Supported |  |
| Accessing criminal records/missing person | H | H | M | Supported |  |
| Forms based incident report | Filing field report | H | H | H | Supported |  |
| 2. *Wideband* |   |   |  |  |  |  |  |
| Messages | E-mail possibly with attachments | Routine e-mail message | M | M | L | Supported |  |
| Data Talk‑around/direct mode operation | Direct unit to unit communication without additional infrastructure | Direct handset to handset, on-scene localized communications | H | H | H | Proposals being considered in 3GPP for this capability in LTE |  |
| Database interaction (medium record size)  | Forms and records query | Accessing medical records | H | H | M | Supported |  |
| Lists of identified person/missing person  | H | H | H | Supported |  |
| GIS (geographical information systems) | H | H | H | Supported |  |
| Text file transfer | Data transfer | Filing report from scene of incident | M | M | M | Supported |  |
| Records management system information on offenders | H | M | L | Supported |  |
| Downloading legislative information | M | M | L | Supported |  |
| Image transfer | Download/upload of compressed still images | Biometrics (finger prints) | H | H | M | Supported |  |
| ID picture | H | H | M | Supported |  |
| Building layout maps | H | H | H | Supported |  |
| Telemetry | Location status and sensory data | Vehicle status | H | H | H | Supported |  |
| Security  | Priority access | Critical care | H | H | H | Supported |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Application** | **Feature** | **PPDR Example** | **Importance(1)** | **3GPP Technology Based System Capability****(See Note A, B, C)** | **NON IMT Technologies** |
| **PP (1)** | **PP (2)** | **DR** |  |  |
| Video | Download/upload compressed video | Video clips | M | L | L | Supported |  |
| Patient monitoring (may require dedicated link) | M | M | M | Supported |  |
| Video feed of in-progress incident | H | H | M | Supported |  |
| Interactive | Location determination | 2-way system  | H | H | M | Supported |  |
| Interactive location data | H | H | H | Supported |  |
| 3. *Broadband* |   |   |  |  |  |  |  |
| Database access | Intranet/Internet access | Accessing architectural plans of buildings, location of hazardous materials | H | H | H | Supported |  |
| Web browsing | Browsing directory of PPDR organization for phone number | M | M | L | Supported |  |
|  |
| Robotics control | Remote control of robotic devices | Bomb retrieval robots, imaging/video robots | H | H | M | Supported |  |
| Video | Video streaming, live video feed | Video communications from wireless clip-on cameras used by in building fire rescue | H | H | H | Supported |  |
| Image or video to assist remote medical support | H | H | H | Supported |  |
| Surveillance of incident scene by fixed or remote controlled robotic devices | H | H | M | Supported |  |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Assessment of fire/flood scenes from airborne platforms | M | H | M | Supported |  |
| Assessment of fire/flood scenes from airborne platforms | M | H | M | Supported |  |
| Imagery | High resolution imagery | Downloading Earth exploration-satellite images | L | L | M | Supported |  |
| Real-time medical imaging | M | M | M | Supported |  |

Editorial note: The format and contents of Table 1 above will have to be reviewed and revised on an ongoing basis in accordance with the decisions made in the editorial exercises in Annex 22 to
Doc. 5A/306 “Working Document holding text to be considered for other working documents”.

## 6.2 Planned evolutions of the standards

### 6.2.1 Some advantages of globally harmonized IMT technology for BB PPDR

Whilst mission critical voice communications will remain a key component of PPDR operations for the next decade or more, new advanced data and video services has become an immediate requirement. For instance, PPDR agencies today use applications such as video for surveillance of crime scenes and of highways, to monitor and conduct operations. Also, there is a growing need for full motion video for other uses such as robotic devices in emergency situations. These types of advanced solutions will be capable of providing local voice, video and data networks, thereby serving the needs of emergency field personnel responding to an incident.

Should harmonized IMT technologies for BB PPDR be implemented initially on a regional basis and with a global vision in the expansion phase, it would drastically reduce the cost of equipment, increase availability of equipment, increase potential for interoperability, provide for a wider range of end-to-end solutions and reduce network infrastructure rollout time.

Some countries are in the process of developing their technical requirements and analysis using example technologies (e.g. IMT standard LTE)

Furthermore introduction of these technologies may enable PPDR agencies and organizations to keep up with increasing demands but also may enable them to implement advanced voice, text, video and other intensive data applications and services designed to enhance service delivery.

In this regard, it should be noted that any development or planning for the use of a future IMT technologies would require that consideration be given to spectrum aspects for broadband PPDR applications.

### 6.2.2 Harmonisation of spectrum and the establishment of harmonized conditions for PPDR

Harmonisation of spectrum for broadband PPDR applications is in a transition phase where related studies and identification of possible tuning-ranges and sub-bands have been started, such as in ITU-R Region 1 (CEPT), aiming to accommodate future operational needs of broadband applications, while significant amounts of spectrum bands are already in use in various countries for narrowband PPDR applications.

Experience has shown that harmonised spectrum has benefits including economic benefits, the development of compatible networks and effective services and the promotion of interoperability of equipment internationally and nationally for those agencies that require national and cross-border cooperation with other PPDR agencies and organizations. Specifically, some potential benefits are as follows:

– economies of scale in the manufacturing of equipment;

– competitive market for equipment procurement;

– increased spectrum efficiency, and easy cross-border coordination;

– increased effective response to disaster relief.

Harmonized conditions can be established for PPDR if:

1) a tuning-range can be identified;

2) a technology standard can be harmonized, such as IMT (LTE).

Harmonized conditions will offer full flexibility for nations/regulators to decide their national dedicated PPDR spectrum chosen from within the tuning-range in accordance with local demands. The LTE technology will then provide full roaming and open for interoperability even if the PPDR spectrum band is not strictly harmonized across borders.

An entire Region can enjoy the benefit of harmonized conditions for BB PPDR if for instance the WRC-15 under AI 1.3 decides to add for Region 1 a 700 MHz tuning range as applicable.

Editorial Note: The text highlighted above in sections 6.2.1.and 6.2.2 need to be reviewed in order to determine where the proposed text should be placed suggested areas are in the Spectrum requirements section (5.2) and the Standardization sections (6.2).

# 7 The needs of developing countries

# 8 Abbreviations/Acronyms

ANNEX 1

Example of a particular PPDR incident scenario using LTE as the representative technology to estimate broadband PPDR spectrum needs

Representative scenario- deploying LTE for PPDR

Use of IMT-LTE for Broadband PPDR system refers to 15 time line events and a typical response sequence based on the number of responders, as well as the broadband resources throughout the incident. The data traffic supporting this response is assumed to be served by a wide area, mobile broadband network. The PPDR agencies also use Project-25 system for voice only. Project-25 system had not been analyzed during this event.

Incident scenario

The scenario includes an accident in which a chemical material truck crashes in the city; the truck hits several cars and the truck tank is damaged. The chemical material starts to leak, and the PPDR agencies start to evacuate the area. Two cars are on fire, the fire is spreading fast, people are injured and some are trapped inside the cars, a nearby building must be evacuated as soon as possible.

The following table shows the time line scenario step by step.

The table includes:

1. Event description

2. Time line from 0 to 6 hours

3. Link type: Project 25 system for Voice and LTE for data

4. Required actions uplink

5. Required actions downlink

6. Total number of users that arrive each time line.

The following PPDR agencies take part during the event:

1. Police

2. Ambulances

3. Fire brigade

4. Hazardous materials response team

5. City control forces.

Event description

Call received at police operation center, and the operation center dispatch immediately broadcasts to all forces to go there as soon as possible. 12 police cars confirm that they on the way to scene. The operation center dispatch sends location information to vehicles’ computers and the police cars also request more information about the area and more GIS information. The dispatch sends them the GIS information and high resolution video of the event from a security camera close to the truck. After 7 minutes, the police cars arrive at the scene and send real time low resolution video from the area. The policemen are getting real time high resolution video from a high resolution security camera via the LTE system on a nearby building in which people are trapped because of the fire. They are also getting GIS information and building information. After 12 minutes, additional police vehicles with 2 chief officers arrive at the scene. They also send real time low resolution video from the area and they receive real time high resolution video from a police helicopter via the LTE system. After 13 minutes, a city control vehicle with 2 officers arrives at the scene. They send real time low resolution video from the area to the city control room and they receive real time high resolution video from a city traffic control camera via the LTE system. After 14 minutes, four ambulances arrive. They request GIS information and send real time high resolution video to their Command Center. They are receiving real time high resolution video from a security camera via the LTE system about the injuries and getting medical information and GIS information. After 15 minutes the fire-brigade arrives, requests GIS information, sends real time medium resolution video from the vehicle’s camera, receives real time medium resolution video from the scene and gets GIS information and building scheme. After 16 minutes, hazardous materials response team arrive and request GIS information, send high resolution pictures in order to verify the chemical liquid with the help of their experts, receive real time medium resolution video from the scene and get GIS information. After 20 minutes, Front Command and Control deployed in the scene area are connecting to the police database. They operate voice conference calls and video conferences; receive real time low resolution video from the helicopter and real time high resolution video from forces inside the building. At this point the Front Command and Control are fully connected to the police database and can use any police information such as cars and people information, real time video, and pictures that can be shared with anyone that needs the information. The information is now fully displayed in the main command and control room of the police and other forces. Commanders can share the information and get full control of the event.

Table 1

Incident scenario time line

|  |
| --- |
| Scenario time line |
| No of users | Used systems | Required action Downlink | Required action Uplink | Link type | Time+ | Part number and event description |
|  |  |  |  |  | 0 | 1. Accident occurs
 |
|  |  |  |  |  | 1 minute | 1. Call received at police Operation Center
 |
| 12 | Project 25 | Call to the closest police vehicles and send location information to vehicles' computer |  | Voice | 2 minutes | 1. Operation Center dispatch sent
 |
| 12 | Project 25 & LTE | Getting GIS information and each policeman (total of 12 ) getting real time high resolution video of the event from security camera close to the truck  | Request for information from Vehicle’s computer+GIS information | Voice+Data | 3 minutes | 1. Police vehicles on the way to scene
 |
| 12 | Project 25 & LTE | Getting real time high resolution video from security camera close to the truck and getting GIS information | Sending real time low resolution video from the area | Voice+Data | 7 minutes | 1. Policemen arrive at scene
 |
| 2 | Project 25 & LTE | Getting real time high resolution video from police helicopter | Sending real time low resolution video from the area | Voice+Data | 12 minutes | 1. Additional police vehicle with 2 chief officers arrives
 |
| 2 | Project 25 & LTE | Getting real time high resolution video from traffic control camera | Sending real time low resolution video from the area | Voice+Data | 13 minutes | 1. City control vehicle with 2 officers arrives at scene
 |
| 12 | Project 25 & LTE  | Getting real time high resolution video from security camera about the injuries and getting GIS information | Request for GIS information and sending real time high resolution video to command center | Voice+Data | 14 minutes | 1. Four ambulances arrival
 |
| 3 | Project 25 & LTE |  Getting real time medium resolution video from scene and get GIS information | Request for GIS information and sending real time medium resolution video from vehicle camera  | Voice+Data | 15 minutes | 1. Fire forces arrival
 |
| 1 | Project 25 & LTE | Getting real time medium resolution video from scene and getting GIS information  | Request for GIS information and sending high resolution pictures  | Voice+Data | 16 minutes | 1. Hazardous materials response team arrival
 |
| 4 | Project 25 & LTE | Video conference , getting real time low resolution video from helicopter and real time high resolution video from scene | Connecting to police database and video conference | Voice+Data | 20 minutes | 1. Front Command and Control deployment
 |
|  | Project 25 & LTE | Total of 36 users who operate 72 applications simultaneously | Total of 36 users who operate 36 applications simultaneously | Voice+Data | 20 minutes | 1. All forces arrived and operational
 |
|  | Project 25 & LTE |  |  | Voice+ Data | 40 minutes | 1. The ambulances leave the area on the way to hospital
 |
|  | Project 25 & LTE |  |  | Voice+ Data | 100 minutes | 1. The forces succeeded to isolate the truck and to close the leak
 |
|  |  |  |  | Voice+ Data | 125 minutes | 1. Chemical material removing to replacement tanks
 |
|  |  |  |  | Voice+ Data | 200 minutes | 1. Replacements tanks are removed from area
 |
|  |  |  |  | Voice+ Data | 250 minutes | 1. The area is clean and checked
 |
|  |  |  |  | Voice+ Data | 360 minutes | 1. End of the event
 |

The following table summarizes the data rate (kbps) for each application during the event:

Table 2

Application data rate

|  |  |  |  |
| --- | --- | --- | --- |
| UL (kbps) | Downlink (kbps) | Description | Application |
| N/A (Project 25) | N/A (Project 25) | Voice call | Voice |
| N/A (Project 25) | N/A | Information from the command center | Request for Information from Vehicle computer |
| 100 | 2000 | Map of the area of the event | GIS Information |
| 2000 | 2000 | Real time video | High resolution video |
| 1000 | 1000 | Real time video | Medium resolution video |
| 500 | 500 | Real time video | Low resolution video |
| 384 | 384 | Video conference application | Video conference |
| 300 | 300 | Image | High resolution picture |

The event occurs within 1.6 km radius area. The area has been closed by the police, and one 45 m antenna mast LTE site gives service to this area.

Analysis

In order to analyze the required spectrum 'Monte Carlo' simulation has been used. The urban clutter loss has been defined to 10 dB. The LTE data (see Report [ITU-R M.2241](http://www.itu.int/pub/R-REP-M.2241) Table 2.2.1-1 for most of the site and equipment parameters):

1. 3 sector site
2. Dual-transmitter and dual-receiver configuration per sector (MIMO)
3. 40W on each diversity antenna[[1]](#footnote-1)
4. 45 m antenna height above ground level
5. Antenna parameters:
	1. 17 dBi antenna gain
6. 65 deg Horizontal pattern (aperture in the horizontal plane at 3 dB (in deg.)
7. 15 deg Vertical pattern (aperture in the vertical plane at 3 dB (in deg.)
8. 3 dB losses (cable losses + connector losses feeder losses)
9. 60 dBm eirp, including cable losses
10. 2 degree downtilt
11. Modulation parameters: QPSK , 16-QAM and 64 QAM
12. Duplex mode – FDD
13. Duty cycle(downlink applications activity factor): 0.5

The LTE UE data (see Report ITU-R M.2241 Table 2.2.1-1 for most of the parameters):

1. 1.5 m antenna height above ground level
2. Omni antenna
3. 0 dBi antenna gain
4. Maximum Transmitter e.i.r.p. (dBm): 21 to 23
5. Average Transmitter e.i.r.p. (dBm): -9
6. Modulation parameters: QPSK , 16-QAM and 64 QAM
7. Duplex mode – FDD
8. Duty cycle (uplink applications activity factor): 0.5

The analysis has been run to analyze part 12 (all the forces arrived to the area). A total of 36 users get information from a few LTE applications (Table 2). Six bandwidths have been checked to get the required spectrum for event part 12 (the maximum required spectrum):

1. 10 MHz
2. 15 MHz
3. 18 MHz (Not a LTE BW based on spec. Has been used just for calculation)
4. 18.8 MHz (Not a LTE BW based on spec. Has been used just for calculation)
5. 20 MHz

The results from each simulation are:

1. Reliability. The reliability in % that the system will be able to give the required data rate and for the required spectrum for all users during the event. The goal is to achieve 95% reliability for the whole area and 90% reliability for a particular application. The reliability results are for each application and composite reliability.

Results

1. The reliability tables results for each bandwidth are shown below:

Table 3

10 MHz reliability results (%)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| High resolution image | Video conference | Low resolution video | Medium resolution video | High resolution video | GIS Information | Whole area | Time line |
| N/A | 81.9 | 76.19 | 58.1 | 35.8 | 36.6 | 47.7 | Downlink |
| 98.9 | 98.8 | 98.6 | 97.9 | 78.9 | N/A | 97.5 | Uplink |

Table 4

15 MHz reliability results (%)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| High resolution image | Video conference | Low resolution video | Medium resolution video | High resolution video | GIS Information | Whole area | Time line |
| N/A | 98.3 | 94 | 79.1 | 65.8 | 66.4 | 72.9 | Downlink |
| 98.9 | 98.9 | 98.8 | 98.2 | 96.2 | N/A | 98.5 | Uplink |

Table 5

18 MHz reliability results (%)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| High resolution image | Video conference | Low resolution video | Medium resolution video | High resolution video | GIS Information | Whole area | Time line |
| N/A | 99 | 98.9 | 93.7 | 86.8 | 88.5 | 94.3 | Downlink |
| 98.9 | 98.9 | 98.8 | 98.2 | 96.5 | N/A | 98.6 | Uplink |

Table 6

18.8 MHz reliability results (%)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| High resolution image | Video conference | Low resolution video | Medium resolution video | High resolution video | GIS Information | Whole area | Time line |
| N/A | 99 | 99 | 96.2 | 93.6 | 94.3 | 97 | Downlink |
| 98.9 | 98.9 | 98.8 | 98.3 | 96.6 | N/A | 98.7 | Uplink |

Table 7

20 MHz reliability results (%)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| High resolution image | Video conference | Low resolution video | Medium resolution video | High resolution video | GIS Information | Whole area | Time line |
| N/A | 99 | 99 | 98.4 | 97.7 | 98 | 98.7 | Downlink |
| 98.9 | 98.9 | 98.9 | 98.3 | 96.8 | N/A | 98.6 | Uplink |

Conclusions of the representative scenario

The reliability results show that the required spectrum for this event is 18.8 MHz for the downlink and 15 MHz for the uplink. The heavy loaded application is the high resolution video at the downlink and uplink paths. The limitation path is the Downlink, since more capacity is required; but if additional users would be using additional high resolution video than the uplink path could be the limitation of the spectrum. The growing demand for broadband mobile LTE PPDR requires a dedicated RF spectrum. Since the present IMT FDD channel arrangements provide equal RF for downlink and uplink, and 18.8 MHz is not part of the LTE specification, 20 MHz X 2 is the required spectrum for this example.

Appendix 1 of Annex 1

Source: Doc. [5A/269](http://www.whttp:/www.itu.int/md/R12-WP5A-C-0269/en)

Example for wireless applications needed for Broadband PPDR system

|  |
| --- |
| **Wireless Applications** |
| **Video** |
| real time video from helicopter |
| real time video fromUnmanned Aircraft |
| real time video from other cameras |
| video transmission from scene |
| **Data** |
| First responders information database connectivity  |
| First responders tactical systems connectivity  |
| First responders cars computers connectivity  |
| First responders citizens information database connectivity  |
| First responders GIS information database connectivity  |
| First responders LPR information database connectivity  |
| First responders vehicle information database connectivity  |
| First responders technical information database connectivity  |
| First responders internal mail connectivity  |
| First responders internal application connectivity  |
| TMS/SMS and MMS capability |
| **Location and GIS** |
| Sending location information |
| Maps and GIS information |
| First responders tactical GIS system connectivity  |
| **Communications**  |
| VOICE call |
| Conference call |
| PTT call to P25  |
| PTT group call |
| Emergency call |
| Talk around between to handsets capability |
| video call |
| **Broadband communications**  |
| Voice over IP connectivity  |
| Mobile base station connectivity  |
| front command and control connectivity  |

Annex 2

Throughput requirements of Broadband PPDR scenarios

Mobile Broad Band technology aiming at wide area coverage constitute an evolution from Narrow Band technology currently applied for mission critical PPDR voice communications in all ITU-R Regions.

A Mobile Broad Band application for the PPDR such as transmission of high resolution images and video requires much higher basic bit-rates than current PPDR technology can deliver.

It should be noted that the new demands for several simultaneous multimedia capabilities (several simultaneous applications running in parallel) over a mobile system presents a huge demand on throughput and high speed data capabilities while the system at the same time shall provide very high peak data rates.

Such demand is particularly challenging when deployed in a localized areas with intensive scene-of-incident requirements where PPDR responders are operating under often very difficult conditions.

For example a 700 MHz LTE PPDR base station deployed to support Broad Band applications in urban environments could typically be tailored to servicing a localized area in the order of 1 km2 or even less offering access to voice, high-speed data, high quality digital real time video and multimedia services, at indicative continuous data rates in the downlink direction in the range of 1 ‑ 10 - 100 - 150 Mbit/s per sector, with a total capacity of 300-450 Mbit/s over the area of 1 km2, with channel bandwidths determined by the particular deployment of the system. Examples of possible applications include:

– high-resolution video communications from portable terminals such as during traffic stops;

– video surveillance of security entry points such as airports with automatic detection based on reference images, hazardous material or other relevant parameters;

– remote monitoring of patients and remote real time video view of the single patient demanding the order of up to 1 Mbit/s. The demand for capacity can easily be envisioned during the rescue operation following a major disaster. This may equate to a net hot spot capacity of over 100 Mbit/s close to a broadband PPDR base station.

Mobile Broad Band systems may have inherent noise and interference trade-offs with data rates and associated coverage. Depending on the technology and the deployed configuration, a single broadband network base station may have different coverage areas in the range of a few hundred metres up to hundred kilometres, offering a wide range in spectrum reuse capability.

Collectively, the high peak data rates, extended coverage and data speeds plus localized coverage area open up numerous new possibilities for BB PPDR applications including tailored area networks as described.

A spectrum throughput and bandwidth calculator has been developed based on the requirements of some Public Safety agencies. This calculator is based on a set of PPDR applications which is based on their current operational experience and their vision of future working practices. The Calculator allows the user to model up to two incident scenes of small, medium, large or very large emergencies. The first incident scene is assumed to take place near the cell edge, and the second incident scene is assumed to be uniformly distributed somewhere in the cell (at a median location/area). The calculator utilizes a blended spectral efficiency model (with a total of 9 spectral efficiency values dependent on the deployment scenario), where background data traffic is modelled with average spectral efficiencies, and the incident scenes are modelled with different spectral efficiencies depending on their location (based on simulations, which are ongoing).

In this calculator, the user may change any boxes highlighted in blue to study different effects (e.g., incident scene size, placement, system deployment topology, bldg. coverage, actual application usage for each incident size/type). While the calculator allows the study of various effects through simulations of various scenarios, it may be noted that there is significant increase in spectral requirements at a cell edge and for large incidents; this requirement becomes overwhelming, likely resulting in the need to offload PS traffic to commercial networks, or deploy an incident scene microcell (CoW). One can also see from the spreadsheet that a medium sized incident near the cell edge and a large incident at a median location require approximately 10+10 MHz of spectrum which is in-line with some other published studies.



Appendix 1 of this Annex provides some of the PPDR scenarios using this calculator to show the throughput and the bandwidth requirements of these Broadband PPDR scenarios. These scenarios include level 1 being a Tanker Spill, Level 2, a Clandestine (Drug) Lab, and Level 3, a Petrochemical Refinery incident. Figure 1 below summarizes the expected public safety equipment and personnel response needed to manage such an incident in a local Chicago (Illinois, USA) suburb.

Appendix 1 of Annex 2

Given the unique mission critical requirements of public safety, it is essential that first responders have unilateral control over sufficient broadband capacity to serve current and future needs. To this end, Motorola Solutions developed a model to evaluate public safety’s broadband wireless requirements by drawing upon existing policies and recent incident feedback. For purposes of this research, Level 1 through Level 3 Hazardous Materials Incidents were considered: Level 1 being a Tanker Spill, Level 2, a Clandestine (Drug) Lab, and Level 3, a Petrochemical Refinery incident. Figure 1 below summarizes the expected public safety equipment and personnel response needed to manage such an incident in a local Chicago (Illinois, USA) suburb.[[2]](#footnote-2)

Figure 1

Typical Response Scope for Level 1-3 Hazardous Materials Incidents



As is clearly evident in Figure 1, even the lowest level incident, Level 1, will elicit considerable response from a variety of public safety agencies that will all arrive on the scene needing broadband services.

The incident scene broadband demands are classified as follows based on usage:

**1 Individual (Person/Vehicle) CAD overhead functions**: The classification includes incident data, GPS information, biosensors and other status, messaging, and queries. Each station individually consumes relatively low down/uplink bandwidth but in aggregate usage can be significant across many users.

**2 Incident Scene database lookups/downloads and information searches**: The classification includes the download of manuals, incident scene images, maps and topography information, building plans, etc. This use case has the unique requirement that, in general, the information is needed quickly as incident commanders initially assess the scene and develop a strategy. The model assumes that all expected initial data is downloaded and available with the first 10 minutes of the incident. The demands are scaled with the incident size and complexity.

**3 Video**: This classification of usage is comprised of personal video cameras for workers operating in the hot-zone, incident scene (car) video positioned around the perimeter, and cameras deployed within the scene. The video is uplinked via the network and a subset of the streams (switchable on command) is down-linked to the on-scene command center. Rates of 400kbps (QVGA 320x240 @ 30fps) and 1.2 Mbps (1280x960 @ 30fps) are used and the number of each type of video stream is scaled with the size and complexity of the incident.

Figure 2 below summarizes the results of the analysis where the bandwidth demands for both uplink and downlink are compared with the expected *average* capacity of a single LTE serving sector (*cell edge* performance, especially on the uplink, would be considerably less and obviously under optimistic conditions peak data rates can be much higher). A “background” load of 20% is added to the total demand assuming this would be a minimum “base load” for other non-incident related, nominal activities across the sector coverage area.

Figure 2

Broadband Wireless Capacity Implications



LTE spectrum requirement observations

The results shown in Figure 2 clearly show that for the environment applying in the United States of America, 10 MHz (5+5) of capacity is insufficient to service the uplink demands for even a Level 1 incident. On the other hand, although 10+10 is still deficient for the ideal Level 3 workload, it services the Level 1 and Level 2 incident demands and comes much closer to providing reasonable capability for the Level 3 case.

It is estimated that in the U.S., a Level 2 incident occurs once a week in a large metropolitan city with a population in the millions, such as Chicago, once a month in a large suburb with a population upwards of 100,000, and two times a year in a small suburb with a population in the tens of thousands.

ANNEX 3

Methodology to calculate spectrum requirement

Table 1

Methodology

|  |  |
| --- | --- |
| **IMT-2000 methodology (Recommendation ITU-R M.1390)** | **Methodology** |
| **A Geography** |  |
| **A1** Operational Environment Combination of user mobility and user mobility. Usually only analyse most significant contributors. | **A1** PPDR user density is much lower and more uniform. PPDR users roam from one environment to another as they respond to emergencies. PPDR systems are usually designed to cover all environments (i.e., wide‑area network provides in-build­ing coverage). Instead of analyzing by physical environment, assume that there will likely be multiple overlapping systems each providing different services (narrowband, wideband, and broadband). Each service environment will probably operate in a different frequency band with different network architectures. Analyse three overlapping urban “service environments”: narrowband, wideband, broadband. |
|  |
|  |
| **A2** Direction of calculation | **A2** Usually separate calculations for uplink and downlink due to asymmetry in some services |
| **A3** Representative cell area and geometry for each environment type | **A3** Average cell radius of radius to vertex for hexagonal cells |
| **A4** Calculate area of typical cell | **A4** Omni cells ＝ πR2Hexagonal cells ＝ 2.6 · R23-sector hex＝ 2.6/3 · R2 |
|
|
| **B** Market & traffic |  |
| **B1** Services offered | **B1** Net user bit rate (kbit/s) for each of the four PPDR service environments: narrowband voice, narrowband data, wideband image, broadband video.  |
| **B2** Population density Persons per unit of area within each environment. Population density varies with mobility | **B2** Total PPDR user population within the total area under consideration. Divide PPDR population by total area to get PPDR population density.  PPDR users are usually separated into well-defined categories by mission. Example:Category Population Regular Police 25848 Special Police Functions 5169 Police Civilian Support 12924 Fire Suppression 7755 Emergency Medical service 1292 General Government Service 130 Other PPDR users 5039 **Total PPDR population 58157**Area under consideration. Area within well-defined geographic or political boundaries.  Example: City of Wuhan  1 550 km2 PPDR population density  PPDR population/area Example: Wuhan  37.5 PPDR/km2 |
| **B3** Penetration ratePercentage of persons subscribing to a service within an environment. Person may subscribe to more than one service | **B3** Similar table.Rows are services, such as voice, data, video Columns are “service environments”, such as narrowband, wideband, and broadband. May collect penetration rate into each “service environment” separately for each PPDR category and then calculate composite PPDR penetration rate.Example: *Category Population* *Penetration* (NB Voice) Regular Police 25848 100% Special Police Function 5169 20% Police Civilian Support 12924 10% Fire Suppression 7755 70% Emergency Medical service 1292 50%General Government Service 130 40%Other PPDR users 5039 40%**Total PPDR Population 58 157** **Narrowband Voice PPDR Population 36807.9**PPDR penetration rate for narrowband “service environment” and voice “service”: Sum (Pop  Pen)/sum(Pop)  63.2% |
| **B4** Users/cellNumber of people subscribing to service within cell in environment | **B4** Users/cell Pop density  Pen Rate  Cell area |
| **B5** Traffic parameters Busy hour call attempts: average number of calls/sessions attempted to/from average user during a busy hourEffective call duration  Average call/session duration during busy hourActivity factor Percentage of time that resource is actually used during a call/session. Example: bursty packet data may not use channel during entire session. If voice vocoder does not transmit data during voice pauses  | **B5** Calls/busy hourSources: current PPDR data and prediction datas/call 0-100% |
| **B6** Traffic/userAverage traffic generated by each user during busy hour | **B6** Call-seconds/userBusy hour attempts  Call duration  Activity factor |
| **B7** Offered traffic/cell Average traffic generated by all users within a cell during the busy hour (3 600 s) | **B7** Erlangs Traffic/user  User/cell/3 600 |
| **B8** Quality of service functionOffered traffic/cell is multiplied by typical frequency reuse cell grouping size and quality of Service factors (blocking function) to estimate offered traffic/cell at a given quality level | One carrier is applied in TD-LTE system. Group size is 1. |
| Group size |  |
| Traffic per group | =Traffic/cell (E) |
| Service channels per group | Use 1% blocking. Erlang B factor probably close to 1.5. Need to consider extra reliability for PPDR systems, excess capacity for peak emergencies, and number of channels likely to be deployed at each PPDR antenna site. Technology modularity may affect number of channels that can be deployed at a site |
| **C** Technical and system considerations |  |
| **C1** Service channels per cell to carry offered load | **C1** Service channels per cell  Service channels per group/Group size |
| **C2** Service channel bit rate (kbit/s) | **C2** Service channel bit rate  Net user bit rate Overhead factor  Coding factor |
| Equals net user bit rate plus additional increase in loading due to coding and/or overhead signalling, if not already included | If vocoder output  4.8 kbit/s, FEC  2.4 kbit/s, and Overhead  2.4 kbit/s, then Channel bit rate  9.6 kbit/s |
| **C3** Calculate traffic (Mbit/s)Total traffic transmitted within area under study, including all factors | **C3** Total traffic Service channels per cell x service channel bit rate |
| **C4** Net system capability Measure of system capacity for a specific technology. Related to spectral efficiency | **C4** Calculate for typical narrowband voice, narrowband data, wideband image and broadband video, spectrum efficiency based on simulation results. |
| **D** Spectrum results |  |
| **D1-D4** Calculate individual components (each cell in service vs environment matrix | **D1-D4** Calculate for each cell in service vs. “service environment” matrix |
| **D5** Weighting factor (alpha) for busy hour of each environment relative to busy hour of other environments, may vary from 0 to 1 | **D5** If all environments have coincident busy hours, then alpha  1Freqes  Freq  alpha requirements in D1‑D4 |
| **D6** Adjustment factor (beta) for outside effects – multiple operators/networks, guard bands, band sharing, technology modularity | **D6** Freq(total)  beta  sum(alpha  Freqes) |

Application of the methodology to the calculation of spectrum requirements for Wuhan city in China

According to above modified method, the frequency band based on TD-LTE system is predicted, considering voice (including point-to-point downlink and uplink and point-to-multipoint downlink and uplink), narrow band data, image and video. Packet data is carried in TD-LTE system, the quality of the voice service focus on time delay, corresponding spectrum efficiency is a litter bit low, shown in Table 1. The spectrum efficiency of Point-to-point uplink and downlink is 0.2 Mbit/s/cell/MHz; In order to guarantee the quality of cell edge, corresponding spectrum efficiency of point-to-multipoint downlink is a little bit lower, that is 0.1 Mbit/s/cell/MHz.

To narrow band data and image, it needs to be differentiated the average spectrum efficiency and edge spectrum efficiency. According to simulation results, average spectrum efficiency uplink is 1.2 Mbit/s/cell/MHz, however, the edge of spectrum efficiency uplink is only 0.1 Mbit/s/cell/MHz; Average spectrum efficiency downlink is 1.6 Mbit/s/cell/MHz, however, the edge of spectrum efficiency uplink is only 0.1 Mbit/s/cell/MHz. Average spectrum efficiency is applied to uplink and downlink in this report.

To wide band video service, spectrum efficiency is calculated by factoring average spectrum efficiency and edge spectrum efficiency, shown in Table 3.

Table 2

Spectrum efficiency of TD-LTE voice

|  |  |  |
| --- | --- | --- |
| Parameters of voice | Value | Unit |
| Band（MHz) | 20 |  |
| Frequency Reuse factor | 1 |  |
| Point-to-point uplink spectrum efficiency | 0.2 | Mbit/s/cell/MHz |
| Point-to-point downlink spectrum efficiency | 0.2 | Mbit/s/cell/MHz |
| Point-to-multipoint downlink spectrum efficiency | 0.1 | Mbit/s/cell/MHz |

Table 3

Spectrum efficiency of TD-LTE narrow band data and image

|  |  |  |
| --- | --- | --- |
| Parameters of voice | Value | Unit |
| Band（MHz) | 20 |  |
| Frequency Reuse factor | 1 |  |
| Uplink average spectrum efficiency | 1.2 | Mbit/s/cell/MHz |
| Uplink edge spectrum efficiency | 0.1 | Mbit/s/cell/MHz |
| Downlink average spectrum efficiency | 1.6 | Mbit/s/cell/MHz |
| Downlink edge spectrum efficiency | 0.1 | Mbit/s/cell/MHz |

Table 4

Spectrum efficiency of TD-LTE video

|  |  |  |
| --- | --- | --- |
| Parameters of voice | Value | Unit |
| Band（MHz) | 20 |  |
| Frequency Reuse factor | 1 |  |
| Spectrum efficiency adjustment factor/ Edge proportion | 0.7 |  |
| Uplink spectrum efficiency | 0.437 | Mbit/s/cell/MHz |
| Downlink spectrum efficiency | 0.536 | Mbit/s/cell/MHz |

Wuhan city is capital of Hubei province and centre of politics, economy and culture, which located in the centre of China. It’s urban and main suburb cover 1 550 km2. It is predicted that population of 2 020 will be about 20 million.

The PPDR is categorized as 4 classes that are police, other police, police civilian support, and fire. The respective probable number is shown as following

Table 5

PPDR population of Wuhan city in 2020

|  |  |
| --- | --- |
| PPDR category | PPDR population |
| Police | 25848 |
| Special police function | 5169 |
| Police civilian support | 12924 |
| Fire | 7755 |
| Emergency medical service | 1292 |
| General government service | 130 |
| Other PPDR users | 5039 |

Service model of voice and data are from Report ITU-R M.2033.

Table 6

Spectrum requirement of TD-LTE Voice

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| A | Geographic considerations | 　 | 　 | 　 | 　 |
| A1 | Select operational environment typeEach environment type basically forms a column in calculation spreadsheet. Do not have to consider all environments, only the most significant contributors to spectrum requirements. Environments may geographically overlap.No user should occupy any two operational environments at one time | 　 | Urban pedestrian and mobile | Urban pedestrian and mobile | 　 |
| A2 | Select direction of calculation, uplink vs downlink or combined | 　 | Uplink | Downlink | 　 |
| A3 | Representative cell area and geometry for each operational environment type，(radius of vertex for sectored hexagonal cells km） | 　 | 1.5 | 　 |
| A4 | Calculate representative cell area hexagonal = 2.6 • r\*r | 　 | 5.85 | 　 |
|  |  |  |  |  |  |
| B | Market and traffic considerations | 　 | 　 | 　 | 　 |
| B1 | Telecommunication services offered(kbit/s) | 　 | 　 | 　 | 　 |
| B2 | 　 | 　 | 　 | 　 | 　 |
| 　 | Total population  | 　 | 58157 | 　 | 　 |
| 　 | 　 | 　 | Population (POP) by PPDR category  | Penetration (PEN) rate within PPDR category | 　 |
| 　 | 　 | Police | 25848 | 1 | 　 |
| 　 | 　 | Special police function | 5169 | 0.2 | 　 |
| 　 | 　 | Police civilian support | 12924 | 0.1 | 　 |
| 　 | 　 | Fire | 7755 | 0.7 | 　 |
|  |  | Emergency Medical service | 1292 | 0.5 |  |
|  |  | General Government Service | 130 | 0.4 |  |
|  |  | Other PPDR users | 5039 | 0.4 |  |
| 　 | 　 | 　 | 36807.9 | 　 | 　 |
| 　 | Area under consideration | 　 | 1550 | km2 | 　 |
| 　 | Number of persons per unit of area within the environment under consideration. Population density may vary with mobility Potential user per km2 | 　 | 37.5 | POP/km2 | 　 |
| 　 | 　 | 　 | Population (POP) by PPDR category  | Penetration (PEN) rate within PPDR category | 　 |
| B3 | Penetration rate | Police | 25848 | 0.481  | 　 |
| 　 | 　 | Special police function | 5169 | 0.024  | 　 |
| 　 | 　 | Police civilian support | 12924 | 0.025  | 　 |
| 　 | 　 | Fire | 7755 | 0.106  | 　 |
|  |  | Emergency medical service | 1292 | 0.011 |  |
|  |  | General government service | 130 | 0.001 |  |
|  |  | Other PPDR users | 5039 | 0.034 |  |
| 　 | 　 | 　 | 0.34  | using voice | 　 |
| B4 | The number of cell | 　 | 265 | 　 | 　 |
| Users/cell | 　 | 139.58  | 　 | 　 |
| B5 | Traffic parameters | 　 | Uplink | Downlink |
| 　 | 　 | 　 | 　 | Point-to-Point | Point-to-Multipoint |
| 　 | Busy hour call attempts (BCHA) (Calls/busy hour) | From PSWAC | 0.0073284E/ busy hour | 0.0463105E/ busy hour | 　 |
| 　 | 　 | 　 | 　 | 0.007718417 | 0.038592083 |
| 　 | Average number of calls/sessions attempted to/from average user during busy hour | 　 | 3.54  | 1.05  | 5.24  |
| 　 | Average call/session duration during busy hours Seconds/call | 　 | 7.88  | 26.53  | 26.53  |
| 　 | Activity factor | 　 | 1.00  | 1.00  | 1.00  |
| B6 | Average traffic in call-seconds generated by each user during busy hour  | 　 | 27.86  | 27.79  | 138.93  |
| 　 | 　 | 　 | 　 | 　 | 　 |
| B7 | Average traffic generated by all userswithin a cell during the busy hour (3 600 s)Erlangs | 　 | 1.08  | 1.08  | 5.39  |
| B8 | Establish quality of service (QOS) function parameters | 　 | 1.5 | 1.5 | 1.5 |
| 　 | frequency reuse factor | 　 | 1 | 1 | 1 |
| 　 | Traffic per cell | 　 | 1.08  | 1.08  | 5.39  |
| 　 | Total Traffic per cell | 　 | 1.62  | 1.62  | 8.08  |
|  |  |  |  |  |  |
| C | Technical and system considerations | 　 | 　 | 　 | 　 |
| C1 | Total Traffic per cell | 　 | 1.62  | 1.62  | 8.08  |
| C2 | Bitrate（kbit/s)(12.2k AMR，about 16k) | 　 | 16.00  | 16.00  | 16.00  |
| C3 | Calculate traffic （Mbit/s) | 　 | 0.026  | 0.026  | 0.129  |
| C4 | Frequency Efficiency | 　 | 0.200  | 0.200  | 0.1 |
|  |  |  |  |  |  |
| D | Spectrum results | 　 | 　 | 　 | 　 |
| D1 | 　 | 　 | 0.13  | 0.13  | 1.29  |
| D2 | Weighting factor for each environment （α ） | 　 | 1.00  | 1.00  | 1 |
| D3 | Adjustment factor（β ） | 　 | 1.00  | 1.00  | 1 |
| D4 | Calculate total spectrum(MHz) | 　 | 1.55  |

Table 7

Spectrum requirement of TD-LTE narrow band data

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| A | Geographic considerations | 　 | 　 | 　 | 　 |
| A1 | Select operational environment typeEach environment type basically forms a column in calculation spreadsheet. Do not have to consider all environments, only the most significant contributors to spectrum requirements. Environments may geographically overlap.No user should occupy any two operational environments at one time | 　 | Urban pedestrian and mobile | Urban pedestrian and mobile | 　 |
| A2 | Select direction of calculation, uplink vs downlink or combined | 　 | Uplink | Downlink | 　 |
| A3 | Representative cell area and geometry for each operational environment type，(radius of vertex for sectored hexagonal cells km） | 　 | 1.5 | 　 |
| A4 | Calculate representative cell area hexagonal = 2.6 • r\*r | 　 | 5.85 | 　 |
|  |  |  |  |  |  |
| B | Market and traffic considerations | 　 | 　 | 　 | 　 |
| B1 | Telecommunication services offered(kbit/s) | 　 | 　 | 　 | 　 |
| B2 | 　 | 　 | 　 | 　 | 　 |
| 　 | Total population  | 　 | 58157 | 　 | 　 |
| 　 | 　 | 　 | Population (POP) by PPDR category  | Penetration (PEN) rate within PPDR category | 　 |
| 　 | 　 | Police | 25848 | 0.5 | 　 |
| 　 | 　 | Special police function | 5169 | 0.05 | 　 |
| 　 | 　 | Police civilian support | 12924 | 0.05 | 　 |
| 　 | 　 | Fire | 7755 | 0.35 | 　 |
|  |  | Emergency medical service | 1292 | 0.2 |  |
|  |  | General government service | 130 | 0.2 |  |
|  |  | Other PPDR users | 5039 | 0.21 |  |
| 　 | 　 | 　 | 18162.8 | 　 | 　 |
| 　 | Area under consideration | 　 | 1550 | km2 | 　 |
| 　 | Number of persons per unit of area within the environment under consideration. Population density may vary with mobility Potential user per km2 | 　 | 37.5 | 　 | 　 |
| 　 | 　 | 　 | Population (POP) by PPDR category  | Penetration (PEN) rate within PPDR category | 　 |
| B3 | Penetration rate | Police | 25848 | 0.240  | 　 |
| 　 | 　 | Special police function | 5169 | 0.006  | 　 |
| 　 | 　 | Police civilian support | 12924 | 0.012  | 　 |
| 　 | 　 | Fire | 7755 | 0.053  | 　 |
|  |  | Emergency medical service | 1292 | 0.05 |  |
|  |  | General government service | 130 | 0 |  |
|  |  | Other PPDR users | 5039 | 0.02 |  |
| 　 | 　 | 　 | 0.39 | 　 | 　 |
| B4 | The number of cell | 　 | 265 | 　 | 　 |
| Users/cell | 　 | 68.46  | 　 | 　 |
| B5 | Traffic parameters | 　 | Uplink | Downlink | 　 |
| 　 | Busy hour call attempts (BCHA) (Calls/busy hour) | 　 | 30.00  | 30.00  | 　 |
| 　 | kbit/date | 　 | 80.00  | 80.00  | 　 |
| 　 | Activity factor | 　 | 1.00  | 1.00  | 　 |
| B6 | Average traffic in call-seconds generated by each user during busy hour  | 　 | 2400.00  | 2400.00  | 　 |
| 　 | 　 | 　 | 　 | 　 | 　 |
| B7 | Average traffic generated by all userswithin a cell during the busy hour (3 600 s)Erlangs Throughput(kbps) | 　 | 0.67  | 0.67  | 　 |
| B8 | Establish quality of service (QOS) function parameters | 　 | 1.5 | 1.5 | 　 |
| 　 | Frequency reuse factor | 　 | 1 | 1 | 　 |
| 　 | Traffic/user in a cell Throughput/ kbps | 　 | 1.00  | 1.00  | 　 |
| 　 | 　 | 　 | 　 | 　 | 　 |
|  |  |  |  |  |  |
| C | Technical and system considerations | 　 | 　 | 　 | 　 |
| C1 | Total Throughput / Mbps | 　 | 0.07  | 0.07  | 　 |
| C2 | Frequency Efficiency | 　 | 1.200  | 1.600  | 　 |
|  |  |  |  |  |  |
| D | Spectrum results | 　 | 　 | 　 | 　 |
| D1 | 　 | 　 | 0.06  | 0.04  | 　 |
| D2 | Weighting factor for each environment （α ） | 　 | 1.00  | 1.00  | 　 |
| D3 | Adjustment factor（β ） | 　 | 1.00  | 1.00  | 　 |
| D4 | Total Spectrum(MHz) | 　 | 0.10  |

Table 8

Spectrum requirement of TD-LTE image

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| A | Geographic considerations | 　 | 　 | 　 | 　 |
| A1 | Select operational environment typeEach environment type basically forms a column in calculation spreadsheet. Do not have to consider all environments, only the most significant contributors to spectrum requirements. Environments may geographically overlap.No user should occupy any two operational environments at one time | 　 | Urban pedestrian and mobile | Urban pedestrian and mobile | 　 |
| A2 | Select direction of calculation, uplink vs downlink or combined | 　 | Uplink | Downlink | 　 |
| A3 | Representative cell area and geometry for each operational environment type，(radius of vertex for sectored hexagonal cells km） | 　 | 1.3 | 　 |
| A4 | Calculate representative cell area hexagonal = 2.6 • r\*r | 　 | 5.85 | 　 |
|  |  |  |  |  |  |
| B | Market and traffic considerations | 　 | 　 | 　 | 　 |
| B1 | Telecommunication services offered(kbit/s) | 　 | 　 | 　 | 　 |
| B2 | 　 | 　 | 　 | 　 | 　 |
| 　 | Total population  | 　 | 58157 | 　 | 　 |
| 　 | 　 | 　 | Population (POP) by PPDR category  | Penetration (PEN) rate within PPDR category | 　 |
| 　 | 　 | Police | 25848 | 0.6 | 　 |
| 　 | 　 | Special police function | 5169 | 0.05 | 　 |
| 　 | 　 | Police civilian support | 12924 | 0.01 | 　 |
| 　 | 　 | Fire | 7755 | 0.3 | 　 |
|  |  | Emergency medical service | 1292 | 0.2 |  |
|  |  | General government service | 130 | 0.2 |  |
|  |  | Other PPDR users | 5039 | 0.24 |  |
| 　 | 　 | 　 | 19908.4 | 　 | 　 |
| 　 | Area under consideration | 　 | 1550 | km2 | 　 |
| 　 | Number of persons per unit of area within the environment under consideration. Population density may vary with mobility Potential user per km2 | 　 | 37.5 | 　 | 　 |
| 　 | 　 | 　 | Population (POP) by PPDR category  | Penetration (PEN) rate within PPDR category | 　 |
| B3 | Penetration rate | Police | 25848 | 0.289  | 　 |
| 　 | 　 | Special police function | 5169 | 0.006  | 　 |
| 　 | 　 | Police civilian support | 12924 | 0.002  | 　 |
| 　 | 　 | Fire | 7755 | 0.046  | 　 |
|  |  | Emergency medical service | 1292 | 0.005 |  |
|  |  | General government service | 130 | 0 |  |
|  |  | Other PPDR users | 5039 | 0.023 |  |
| 　 | 　 | 　 | 0.40  | 　 | 　 |
| B4 | The number of cell | 　 | 265 | 　 | 　 |
| Users/cell | 　 | 75.19  | 　 | 　 |
| B5 | Traffic parameters | 　 | Uplink | Downlink | 　 |
| 　 | Busy hour call attempts (BCHA) (Calls/busy hour) | 　 | 6.00  | 6.00  | 　 |
| 　 | kbit /Image | 　 | 8000.00  | 8000.00  | 　 |
| 　 | Activity factor | 　 | 1.00  | 1.00  | 　 |
| B6 | Average traffic in call-seconds generated by each user during busy hour  | 　 | 48000.00  | 48000.00  | 　 |
| 　 | 　 | 　 | 　 | 　 | 　 |
| B7 | Average traffic generated by all userswithin a cell during the busy hour (3 600 s)Erlangs Throughput(kbps) | 　 | 13.33  | 13.33  | 　 |
| B8 | Establish quality of service (QOS) function parameters | 　 | 1.5 | 1.5 | 　 |
| 　 | Frequency Reuse factor | 　 | 1 | 1 | 　 |
| 　 | Traffic/user in a cell Throughput/ kbps | 　 | 20.00  | 20.00  | 　 |
| 　 | 　 | 　 | 　 | 　 | 　 |
|  |  |  |  |  |  |
| C | Technical and system considerations | 　 | 　 | 　 | 　 |
| C1 | Total Throughput / Mbps | 　 | 1.50  | 1.50  | 　 |
| C2 | Frequency Efficiency | 　 | 1.200  | 1.600  | 　 |
|  |  |  |  |  |  |
| D | Spectrum results | 　 | 　 | 　 | 　 |
| D1 | 　 | 　 | 1.25  | 0.94  | 　 |
| D2 | Weighting factor for each environment （α ） | 　 | 1.00  | 1.00  | 　 |
| D3 | Adjustment factor（β ） | 　 | 1.00  | 1.00  | 　 |
| D4 | Total Spectrum(MHz) | 　 | 2.19  |

Table 9

Spectrum requirement of TD-LTE video

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| A | Geographic considerations | 　 | 　 | 　 | 　 |
| A1 | Select operational environment typeEach environment type basically forms a column in calculation spreadsheet. Do not have to consider all environments, only the most significant contributors to spectrum requirements. Environments may geographically overlap.No user should occupy any two operational environments at one time | 　 | Urban pedestrian and mobile | Urban pedestrian and mobile | 　 |
| A2 | Select direction of calculation, uplink vs downlink or combined | 　 | Uplink | Downlink | 　 |
| A3 | Representative cell area and geometry for each operational environment type，(radius of vertex for sectored hexagonal cells km） | 　 | 1.5 | 　 |
| A4 | Calculate representative cell area hexagonal = 2.6 • r\*r | 　 | 5.85 | 　 |
|  |  |  |  |  |  |
| B | Market and traffic considerations | 　 | 　 | 　 | 　 |
| B1 | Telecommunication services offered(kbit/s) | 　 | 　 | 　 | 　 |
| B2 | 　 | 　 | 　 | 　 | 　 |
| 　 | Total population  | 　 | 58157 | 　 | 　 |
| 　 | 　 | 　 | Population (POP) by PPDR category  | Penetration (PEN) rate within PPDR category | 　 |
| 　 | 　 | Police | 25848 | 0.2 | 　 |
| 　 | 　 | Special police function | 5169 | 0.04 | 　 |
| 　 | 　 | Police civilian support | 12924 | 0.02 | 　 |
| 　 | 　 | Fire | 7755 | 0.4 | 　 |
|  |  | Emergency medical service | 1292 | 0.1 |  |
|  |  | General government service | 130 | 0.3 |  |
|  |  | Other PPDR users | 5039 | 0.1 |  |
| 　 | 　 | 　 | 9694.4 | 　 | 　 |
| 　 | Area under consideration | 　 | 1550 | km2 | 　 |
| 　 | Number of persons per unit of area within the environment under consideration. Population density may vary with mobility Potential user per km2 | 　 | 37.5 | 　 | 　 |
| 　 | 　 | 　 | Population (POP) by PPDR category  | Penetration (PEN) rate within PPDR category | 　 |
| B3 | Penetration rate | Police | 25848 | 0.096  | 　 |
| 　 | 　 | Special police function | 5169 | 0.005  | 　 |
| 　 | 　 | Police civilian support | 12924 | 0.005  | 　 |
| 　 | 　 | Fire | 7755 | 0.061  | 　 |
|  |  | Emergency medical service | 1292 | 0.002 |  |
|  |  | General government service | 130 | 0.001 |  |
|  |  | Other PPDR users | 5039 | 0.009 |  |
| 　 | 　 | 　 | 0.33  | 　 | 　 |
| B4 | The number of cell | 　 | 265 | 　 | 　 |
| Users/cell | 　 | 36.58  | 　 | 　 |
| B5 | Traffic parameters | 　 | Uplink | Downlink | 　 |
| 　 | Busy hour call attempts (BCHA) (Calls/busy hour) | 　 | 6.00  | 3.00  | 　 |
| 　 | Average traffic in call-seconds generated by each user during busy hour  | 　 | 60.00  | 60.00  | 　 |
| 　 | Activity factor | 　 | 1.00  | 1.00  | 　 |
| B6 | Verage traffic generated by all userswithin a cell during the busy hour (3 600 s)Erlangs Throughput(kbps) | 　 | 360.00  | 180.00  | 　 |
| 　 | 　 | 　 | 　 | 　 | 　 |
| B7 | Average traffic generated by all userswithin a cell during the busy hour (3 600 s)Erlangs Throughput(kbps) | 　 | 3.66  | 1.83  | 　 |
| B8 | Establish quality of service (QOS) function parameters | 　 | 1.5 | 1.5 | 　 |
| 　 | Frequency Reuse factor | 　 | 1 | 1 | 　 |
| 　 | Traffic of all users in a cell Throughput/ kbps | 　 | 3.66  | 1.83  | 　 |
| 　 | Total traffic in a cell Throughput/ kbps | 　 | 5.49  | 2.74  | 　 |
|  |  |  |  |  |  |
| C | Technical and system considerations | 　 | 　 | 　 | 　 |
| C1 | Total Traffic per cell | 　 | 5.49  | 2.74  | 　 |
| C2 | Bitrate（kbit/s)(2MHz) | 　 | 2000.00  | 2000.00  | 　 |
| C3 | Total Throughput / Mbps | 　 | 10.975  | 5.487  | 　 |
| C4 | Frequency Efficiency | 　 | 0.430  | 0.550  | 　 |
|  |  |  |  |  |  |
| D | Spectrum results | 　 | 　 | 　 | 　 |
| D1 | 　 | 　 | 25.52  | 9.98  | 　 |
| D2 | Weighting factor for each environment （α ） | 　 | 1.00  | 1.00  | 　 |
| D3 | Adjustment factor（β ） | 　 | 1.00  | 1.00  | 　 |
| D4 | Total Spectrum(MHz) | 　 | 35.50  |

Frequency prediction is summarised in Table 10.

Table 10

Example narrowband and wideband calculation summaries

|  |  |  |
| --- | --- | --- |
| PPDR category | Wuhan population | Penetration rates |
| Narrowband voice | Narrowband data | Wideband image | broadband video |
| Police | 25848 | 1 | 0.5 | 0.6 | 0.2 |
| Special police function | 5169 | 0.2 | 0.05 | 0.05 | 0.04 |
| Police civilian support | 12924 | 0.1 | 0.05 | 0.01 | 0.02 |
| Fire | 7755 | 0.7 | 0.35 | 0.3 | 0.4 |
| Emergency medical service | 1292 | 0.5 | 0.2 | 0.2 | 0.1 |
| General government service | 130 | 0.4 | 0.2 | 0.2 | 0.3 |
| Other PPDR users | 5039 | 0.4 | 0.21 | 0.24 | 0.1 |
| **Total – PPDR users** | 58157 | 36870 | 18162 | 19908 | 9673 |
| Spectrum (MHz) |  | 1.55 | 0.1 | 2.19 | 35.50 |
| Spectrum in total (MHz) | 39.34 |  |  |  |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Other parameters:** |  |  |  |  |  |
| Environment | Urban pedestrian and mobile |  |  |  |  |
|  |  |  |  |  |  |
| Cell radius (km) | 1.5 |  |  |  |  |
| Study area (km2) | 1550 | (Calculated) |  |  |
| Cell area (km2) | 5.85 | (Calculated) |  |  |
|  |  |  |  |  |  |
|  |  | NB Voice | NB data | WB image | BB Video |
|  |  | Uplink | Uplink | Uplink | Uplink |
| Erlangs per busy hour |  | 0.007328 |  |  | 0.1 |
| Busy hour call attempts |  | 3.54 | 30 | 6 | 6 |
| Effective call duration |  | 7.88s | 80kbit | 8000kbit | 60s |
| Activity factor |  | 1 | 1 | 1 | 1 |
|  |  |  |  |  |  |
|  | NB Voice | NB data | WB image | BB Video |
|  | DL PTP | DL PTM | Downlink | Downlink | Downlink |
| Erlangs per busy hour | 0.00771 | 0.03859 | 　 | 　 | 0.05 |
| Busy hour call attempts | 1.05 | 5.24 | 30 | 6 | 3 |
| Effective call duration | 26.53s | 26.53s | 80kbit | 8000kbit | 60s |
| Activity factor | 1 | 1 | 1 | 1 | 1 |
|  |  |  |  |  |  |
| Group size | 1 |  |  |  |  |
| Grade of service factor | 1.5 |  |  |  |  |
| α factor | 1 |  |  |  |  |
| β factor | 1 |  |  |  |  |

Considering narrow band voice, narrow band data, wide band image and broad band video, total 39.34 MHz is maybe minimum PPDR spectrum according to requirement development of Wuhan city in 2020.

Table 11

Total spectrum requirement of TD-LTE

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Voice/MHz | Narrow data/MHz | Image/MHz | Video/MHz | Total spectrum /MHz |
| 1.55 | 0.1 | 2.19 | 35.5 | **39.34** |

Annex 4

Methodology for the calculation of broadband PPDR
spectrum requirements within CEPT[[3]](#footnote-3)

The frequency ranges used for estimating the necessary spectrum bandwidth are the 400 MHz and 700 MHz ranges. It is assumed that a wide area network would be deployed below 1 GHz in order to reduce the number of necessary cell sites.

A brief description of the methodology used for calculation of spectrum requirements is presented below.

This methodology can be considered as an incident based approach where traffic is summed over several separate incidents and background traffic is then added in order to define the total spectrum requirements.

Methodology for PP1

The methodology used for PP1 scenarios consists of the following 5 steps:

Step 1: Definition of the incidents (scenarios)

Step 2: Estimate the total traffic requirement per incident including background traffic

Step 3: Calculate the link budgets and cell size

Step 4: Estimate the number of incidents that should be taken into account simultaneously per cell

Step 5: Estimate the total spectrum requirement based on assumptions on number of incidents per cell, location of incidents within a cell and spectrum efficiency per incident

Methodology for PP2

The methodology used for PP2 scenarios consists of the following 3 steps:

Step 1: Definition of the PP2 scenarios

Step 2: Estimate of the PP2 scenarios traffic

Step 3: Estimate the total spectrum requirement based on assumptions on location of users within the cell and spectral efficiency

Annex 5

Definitions

Editor's note: These definitions will need reviewed for their relevance and be crosschecked with similar or existing definitions already used within the ITU.

# Public protection and disaster relief

The term Public Protection and Disaster Relief (PPDR) is defined in ITU-R Resolution **646** **(WRC‑12)** as a combination of two key areas of emergency response activity:

• Public Protection – dealing with the maintenance of law and order, protection of life and property, and emergency situations.

• Disaster Relief – 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, natural phenomena, or human activity, and whether developing suddenly or as a result of complex, long-term processes.

# Broadband PPDR scenario

A PPDR scenario is an operational situation in which a combination of different applications is used to manage the event or incident. Scenarios include average day-to-day operations, large emergencies or public events and disasters. Separate scenarios are identified since they are distinct in terms of their characteristics and may impose different requirements for PPDR communications. Scenarios may differ from country to country because they are based on individual sovereign national instructions or guidelines.

# Commercial communication network

A commercial communication network is one that is built and operated by profit-oriented operators in order to offer public communication services.

# Commercial technology standard

A technical standard e.g. GSM, LTE, that is initially or primarily developed as platform for the operation of commercial communication networks.

# Cross-border

PPDR organisations have to assist each other in certain cases, meaning they have to be able to work in foreign countries with the local PPDR organisations and at the same time with their own organisation.

# Day-to-day operation

Day-to-day operations encompass the routine tasks that PPDR agencies conduct within their jurisdiction. Typically these tasks are conducted inside national borders. Generally most PP spectrum and infrastructure requirements are determined using this scenario with the addition of extra capacity to cover unspecified and sudden emergency events.

# PPDR Dedicated network

A network solely designed to fulfil the specific PPDR requirements: this can be a GoGo model (Government Owned, Government Operated), but also a service delivered by a third party (CoCo: Company Owned, Company Operated). Another model is GoCo (network owned by Government, but operated by a third party).

# Disaster

Disasters are situations caused by either natural or human activity. For example, natural disasters include an earthquake, major tropical storm, a major ice storm, floods, etc. Examples of disasters caused by human activity include large-scale criminal incidents or situations of armed conflict. Generally, both the existing PP communications systems and special on-scene communications equipment brought by DR organisations are deployed.

# IMT

International Mobile Telecommunication Systems. IMT specifications and standards are defined in Recommendations ITU-R M.1457 and ITU-R M.2012.

# PPDR Interoperability

PPDR interoperability is described in ITU-R.M2033 as the ability of PPDR personnel from one agency/organisation to communicate by radio with personnel from another agency/organisation, on demand (planned and unplanned) and in real time. There are several elements/components which affect interoperability including, spectrum, technology, network, standards, planning, and available resources. Systems from different vendors, or procured for different countries, should be able to interoperate at a predetermined level without any modifications or special arrangements in other PPDR or commercial networks. Interoperability is also needed in a ‘multi-vendor’ situation where terminals from different suppliers are working on infrastructures from other suppliers.

# Large emergency/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 organisations. In most cases there are either plans in place or there is some time to plan and coordinate the requirements.

# LTE

LTE (Long Term Evolution), marketed as 4G LTE, is a standard for wireless communication of high-speed data for mobile phones and data terminals. The LTE specifications are developed by the 3GPP (3rd Generation Partnership Project, while the standards are written regionally such as in ETSI, TIA, ARIB and other regional Standard Development Organizations.

# Roaming

In wireless telecommunications, roaming is a general term referring to the extension of connectivity service in a network that is different from the home network where the service was registered. Roaming ensures that the wireless device is kept connected to a network, without losing the connection. Traditional (GSM)-Roaming is defined as the ability for a cellular customer to automatically make and receive voice calls, send and receive data, or access other services, including home data services, when travelling outside the geographical coverage area of the home network, by means of using a visited network. This can be done by using a communication terminal or simply just by using the subscriber identity in the visited network.

## Data throughput

A data throughput and spectrum bandwidth calculator should be developed based on the requirements of PPDR agencies. This calculator would use a set of PPDR applications and be based on current operational experience and vision of future working practices.

## Mission critical communications

Mission critical Communications are those communications that are used by PPDR organizations in situations where human life, property and other values for the society are at risk, especially when time is a vital factor. Mission critical communications are secure, reliable and readily available and as a consequence responders cannot afford the risk of having failures in their individual and group communications (e.g. voice and data or video transmissions).”

## PPDR specific standard

A radio communication standard that has been developed specifically for PPDR applications or that is a further development of an already existing (commercial) standard.]

1. 3GPP TS 36.104 version 11.4.0 Release 11 – Table 6.2.1. [↑](#footnote-ref-1)
2. Specifically Posen, Illinois was used and their MABAS (Multi-Agency Box Alarm System) “Box Card” was evaluated with interpretation from Posen PS employees. [↑](#footnote-ref-2)
3. See the latest version of ECC Report 199 (Link ?) for more details on methodology used in CEPT. [↑](#footnote-ref-3)