Study Paper

On

Public Protection and Disaster Relief (PPDR) Communication System

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Table of Contents

Abstract: -

This paper gives a brief overview of the Public Protection and Disaster Relief (PPDR) communications and system requirements for effective PPDR communications. Various technologies prevailing in use for PPDR communications have been discussed. Considering the growing demand for broadband applications, future technologies for PPDR communications have also been discussed.

Technological solutions have been proposed taking into account the present day requirements as well as the problems faced by the PPDR users. The paper concludes by recommending the steps to be taken for realizing effective PPDR communications in India.

1. Public Protection and Disaster Relief (PPDR) communications and the Indian scenario:

1.1. Introduction to PPDR:

During emergency or disaster situations, especially in a country as vast & diverse like India which is highly prone to natural disaster situations like floods, earthquakes, coastal cyclone, manmade disasters like accidents, terrorist attacks etc., communications play an important role in rescue and relief operations.

PPDR stands for Public Protection and Disaster Relief, which clearly caters to two different but interrelated activities. Public Protection is a kind of pre mediated/ pre planned preventive action whereas Disaster Relief deals with activities to be undertaken in the aftermath of an event disrupting the public order such as a disaster.

PPDR activities mainly cover three broad categories namely: -

- **Routine day-to-day activities**, which can be dealt by existing local authorities.
  e.g. - Police, Fire, Ambulance, etc.
- **Major planned events**, which require deployment of additional resources (sufficient time would be available for planning).
  e.g. - Trade Fairs, International Sport events, conferences, etc.
- **Major unforeseen incidents**, which also require deployment of additional resources but within a short time period (some contingency planning will be done to ensure preparedness in anticipation of such incidents).
  e.g. - Tsunamis, Earthquakes, Cyclones, Terrorist attacks, etc.

The agencies providing the PPDR services are called as First Responders. Core PPDR agencies typically include police, fire brigades and emergency medical services. However, there are also other agencies like NDRF, coast guards and border security forces, military and paramilitary forces, custom and excise officers who are also roped in for this purpose at times in emergency situations. They all need resilient communication networks for their day-to-day, emergency and disaster relief operations.

1.2. International definition of PPDR communications

PPDR communications is defined in Resolution **646 (Rev. WRC-15)** as a combination of two key areas of emergency response activity as follows: -

- **Public protection (PP) radio communications: -** Radio communications used by agencies and organizations responsible for dealing with maintenance of law and order, protection of life and property, and emergency situations.

- **Disaster relief (DR) radio communications**: - Radio communications used by agencies and organizations dealing with a serious disruption in the functioning of society, posing a significant, widespread threat to human life, health, property or the environment, whether caused by accident, natural or human activity, and whether suddenly or as a result of complex, long-term processes.

1.3. PPDR communication network/system

A PPDR Communication network can be construed as a highly reliable and secure communication network/system comprising of a single or multiple nodes to take care of emergency communication requirements of the targeted geographical area.

Currently, Indian PPDR agencies rely on narrow-band digital trunking technology like TETRA and P25 systems or old analog systems for their communication in the field, which are primarily meant for voice communication. The PPDR communication networks are at present designed and run by independent state agencies. The PPDR agencies so far are issued license by Department of Telecommunications (DoT) under Captive Mobile Radio Trunking Service (CMRTS) category. Accordingly, Wireless Planning & Coordination Wing (WPC Wing) of DoT allocates spectrum in the designated 300 MHz, 400 MHz or 800 MHz bands. (Please refer clause 1.5)

The current framework has resulted in fragmented spectrum assignments with inefficient use of precious and prime sub-GHz frequency. Despite consuming large amounts of costly spectrum, it does not meet the evolving needs of the public safety and emergency communication such as access to instant messaging, high-quality images and video, mapping and location services, remote control of robots, and other applications. Moreover, individual PPDR agencies have their independent networks in place, which work in silos. This results in inability to have seamless communication and information sharing among the PPDR agencies. This is because their networks are either not inter-operable or they are just not compatible with each other. This deprives the agencies of instant cross-agency coordination and exchange of mission-critical information, which eventually results in ineffective mitigation of safety and disaster situation.

To overcome the limitations of current PPDR communication networks, next generation PPDR communication networks should be deployed with enhanced broadband capabilities, under a unified framework and comprehensive policy. Broadband PPDR (BB-PPDR) using LTE is the optimal choice for an integrated PPDR network providing cutting-edge services standardized by 3GPP in Rel. 12, 13 and 14. LTE broadband trunking, featuring large bandwidths, high data-rates, and IP-based operation, supporting multimedia communication including eMBMS (video) to/from disaster site, is becoming the mainstream in the market, ushering an era of LTE-based public-safety networks.

In view of above, TRAI has recommended setting up a Pan-India integrated Broadband PPDR (BB-PPDR) communication network (to be called "National BB-PPDR Network") based on 3GPP PS-LTE technology, via a hybrid approach using dedicated network in some parts while sharing commercial network in the rest.

1.4. National Digital Communication Policy (NDCP) 2018[2]

National Digital Communications Policy 2018, taken care of developing a comprehensive plan for network preparedness, disaster response relief, restoration and reconstruction as follows:

i) Strengthening network resilience by:

a) Framing and enforcing standard operating procedures to be followed during disasters and natural calamities, including sectoral guidelines for disaster response and recovery applicable to various service providers

b) Establishing institutional framework to promote monitoring of activities, rapid dissemination of early warning disaster notifications and better coordination and collaboration between relevant Ministries / Departments, including the National Disaster Management Authority of India

ii) Developing a Unified Emergency Response Mechanism by:

a) Creating an institutional framework with clearly defined roles and responsibilities, Standard Operating Procedures and technical guidelines

b) Incorporating obligations under the license terms and conditions for implementation of Next Generation 112 services in all areas, based on geolocation technologies, and provide online access to caller location and details to authorized central and state agencies

c) Enforcing obligations of service providers to share infrastructure, and ensure interoperability in emergencies in a network-agnostic, operator-agnostic and technology-agnostic manner.

iii) Enhancing the Public Protection & Disaster Relief (PPDR) plan for India by:

a) Facilitating the establishment of a Pan-India network for Public Protection and Disaster Relief (PPDR)

b) Making necessary spectrum available for PPDR including by establishing INSAT satellite-based mobile communication systems
c) Implementing global and regional harmonized spectrum Plans for PPDR.

1.5. National Frequency Allocation Plan-2018 (NFAP-2018)[5]

The following frequency bands were identified for PPDR communications in NFAP-2018:

IND 18: In Region 3, the frequency ranges 406.1-430 MHz, 440-470 MHz, and 4 940-4 990 MHz are harmonized for Public Protection and Disaster Relief (PPDR) applications. In Region 1, the frequency range 380-470 MHz is harmonized for PPDR applications. Additionally, parts of the frequency range 694-894 MHz may also be considered for PPDR applications. See Resolution 646 (Rev. WRC-15).

The band 450-470 MHz is identified for use by administrations wishing to implement International Mobile Telecommunications (IMT) (see No. 5.286AA of NFAP 2018). The band 406.1-410 MHz is also allocated to radio astronomy service.

Trunked radio systems are operational in the frequency ranges 336-340 MHz paired with 346-350 MHz, 351-358 MHz paired with 361-368 MHz, 380-389.9 MHz paired with 390-399.9 MHz, 410-420 MHz paired with 420-430 MHz, and 806-819 MHz paired with 851-864 MHz. The preferred use of these frequency ranges is as under.

<table>
<tr><th>S.N.</th><th>Frequency (MHz)</th><th>Paired Frequency (MHz)</th><th colspan="2">Proposed Applications/ paired frequency (MHz)</th></tr>
<tr><td>1.</td><td>336-338</td><td>346-348</td><td colspan="2">PMRT</td></tr>
<tr><td>2.</td><td>338-340</td><td>348-350</td><td colspan="2">PMRT</td></tr>
<tr><td>3.</td><td>351-356</td><td>361-366</td><td colspan="2">CMRT</td></tr>
<tr><td>4.</td><td>356-358</td><td>366-368</td><td colspan="2">CMRT</td></tr>
<tr><td rowspan="2">5.</td><td rowspan="2">380-389.9</td><td rowspan="2">390-399.9</td><td>380-387.5 (PPDR)</td><td>390- 397.5 (PPDR)</td></tr>
<tr><td>387.5-390 (CMRT)</td><td>397.5- 400 (CMRT)</td></tr>
<tr><td rowspan="2">6.</td><td rowspan="2">410-420</td><td rowspan="2">420-430</td><td>410-417.5 (PPDR)</td><td>420- 427.5 (PPDR)</td></tr>
<tr><td>417.5-420 (CMRT)</td><td>427.5- 430 (CMRT)</td></tr>
<tr><td>7.</td><td>440-470</td><td>-</td><td colspan="2">Part of 440-470 MHz may be considered for PPDR</td></tr>
<tr><td>8.</td><td>806-811</td><td>851-856</td><td colspan="2">PPDR</td></tr>
<tr><td>9.</td><td>811-814</td><td>856-859</td><td colspan="2">PMRT</td></tr>
<tr><td>10.</td><td>814-819</td><td>859-864</td><td colspan="2">PMRT</td></tr>
<tr><td>11.</td><td>819-824</td><td>864-869</td><td colspan="2">PMRT</td></tr>
<tr><td>12.</td><td>4940-4990</td><td>-</td><td colspan="2">PPDR</td></tr>
</table>

Existing radio trunking systems, not in conformity with the above table, will continue to operate until the end of their lifetime. New systems or expansions of existing systems are encouraged to conform to the above table.

Wideband and broadband PPDR applications shall be in accordance with the channel arrangements that promote harmonization to the greatest extent possible. The harmonization shall also be encouraged for the radio trunking systems in general and, in particular, those operating in conformity with the table above.

Broadband PPDR application will be encouraged in the Frequency Band 410-420 MHz paired with 420-430 MHz

2. Objectives & System requirements for PPDR operations

2.1 Technical, Functional & Operational objectives:

The major objectives of PPDR systems may be regarded as those that relates to the performance capabilities of PPDR systems, how & for what purposes, those systems may be used, how the system operates, is used or deployed, interwork with other systems/agencies and share, roam or offloads capacity. PPDR Radio-communications system have the following objectives: -

i) to support the integration of voice, data, video and image communications as part of a multimedia capability;

ii) to provide additional level(s) of priority, availability and layered security associated with the source, destination and type of information carried over the communication channels used by various PPDR applications and operations (e.g. authentication, air-to- air encryption, end-to end encryption (subscriber device management and application security);

iii) to provide each PPDR agency and organization with user authentication (e.g. public key cryptography) among PPDR agencies and organizations and for their devices prior to granting access to their applications or network resources;

iv) to support operation in extreme or adverse environments (high mobility, heat, cold, dust, rain, water, noise, shock, vibration, extreme temperature, and extreme electromagnetics, etc.);

v) to support robust equipment (e.g. hardware, software, operational and maintenance aspects, long battery life, to meet intrinsic safety requirements). Equipment (handheld or transportable) that functions while the user is in motion is also required. Equipment may also require unique accessories, which could include special microphones (e.g. lapel, in-ear) or design features to enable use while wearing gloves;

vi) to accommodate the use of repeaters for covering long distances between terminals and base stations in rural and remote areas and also for intensive on-scene localized areas;

vii) to provide fast call set-up, one-touch broadcasting (PTT to group) and group call features;

viii) to provide for emergency calls, one-touch emergency alert (emphasizing that this function is used in life threatening situations and should receive the highest level of priority), emergency voice PTTs, and emergency data PTTs (e.g. sending images, real-time video) during PPDR events;

ix) to support information, pull, push and subscription with prioritization;

x) to provide for strong multi-national/multi-agency technical interoperability over multi-network and device technologies in a seamless fashion;

xi) to provide Localized Communication Services (LCS), Relayed Device Mode Communications (RDM), Direct Mode Operation (DMO);

xii) to provide for the ability of PPDR communication systems to interface with other dedicated PPDR and/or commercial systems;

xiii) to be scalable in order to suit small and large agencies, without sacrificing the ability to interoperate;

xiv) to provide for quick deployment of temporary infrastructure and services as well as recovery from failure;

xv) to support continuous use of basic PPDR services in case of infrastructure collapse or failure, e.g. loss of backhaul link between base station and core network;

xvi) to support the need for high level of security without compromising the response time;

xvii) to provide audio quality that ensures the listener is able to understand without repetition, identify the speaker, detect stress in a speaker’s voice, and hear background sounds without interfering with the primary voice communications.

Requirements vii), viii) and xvii) above may be deemed essential for providing mission critical PPDR operations.

xviii) to provide security, including optional end-to-end encryption and secure terminal/network authentication;

xix) to enable communications management to be fully (or partly) controlled by PPDR agencies and organizations through such functions as: dispatch and incident management, instant/dynamic reconfiguration changes to talk groups, guaranteed access controls (including device and application priority pre-emption calls, groups or general calls), spectrum resource availability for multiple PPDR agencies and organizations, and coordination and rerouting;

xx) to support interoperability and interworking between networks (both nationally and for cross border operation) and roaming of both mobile and portable units in emergency and disaster relief situations (including interconnectivity with public networks);

xxi) to provide group communications through the system/network and/or independent of the network (e.g. such as localized communication services, simplex radio and push-to-talk);

xxii) to provide customized and reliable coverage, especially for indoor areas such as underground and inaccessible areas;

xxiii) to allow for the extension of coverage area and/or capacity in rural and remote areas or under severe conditions during emergency and disaster situations;

xxiv) to provide full service continuity, high reliability and sufficient failure tolerance through measures such as redundancy;

xxv) support for isolated sites/stations working in case of backhaul loss, and the possibility to rapidly deploy temporary coverage and capacity, or when there is partial loss of infrastructure;

xxvi) to provide high quality-of-service, including fast call set-up and dialing, push-to-talk, resilience under extreme load, very high call set-up success rate, etc.;

xxvii) to support a wide variety of PPDR applications;

xxviii) to provide for multi-national/multi-agency interoperability at various levels of incident management and chain of command as well as with other, collaborating organizations and/or entities; and

xxix) to have user handsets/devices that are easily useable and configurable with little need for technical expertise.

2.2 Communication scenarios/requirements in a PPDR situation:[6]

The following 8 high priority communication scenarios can be considered for effective PPDR functioning: -

a) Communication between central control station and field personnel at an incident location.
b) Communication between PPDR vehicles and an incident location or control station.
c) Communication between individuals at an incident location.
d) Communication between different PPDR entities.
e) Communication with or between machines (ex: - remotely controlled vehicles).
f) Communication in enclosed spaces (ex: - Tunnels or basements).
g) Communication within remote locations (ex: - mountains, seawaters, valleys, etc).

h) Access to internet or external data sources (including corporate intranets), for accessing relevant information.

2.3 Technical requirements for PPDR communications

(i) The required data rates for PPDR communications may typically range up to 55 Mbps for uplink and 46 Mbps for downlink, depending on the applications deployed by the PPDR agencies.

(ii) PPDR infrastructure may have to support mobility requirements typically ranging from zero to 200kmph or even more, though it may depend on the technology deployed.

(iii) Latency time is expected to be typically less than 1sec for video transmission and high priority voice messages (fast call setup – reducing the response time to access the particular network).

(iv) Key "mission-critical" voice communication requirements for the PPDR communication network are:

- **Fast call set-up –** The calls must be connected instantaneously without any delay because time is the major factor in mission-critical scenarios.
- **Group calling –** With a single button press, one must be able to connect to a group and communicate with all the users in the group instantaneously. This is provided using Push-to-Talk (PTT) feature in current PPDR terminals. PTT is also called "Press-To-Transmit". It works in half-duplex mode. The speaker pushes a button on his/her radio terminal and transmits his/her voice message to other terminal units. When they finish talking, they release the PTT switch and return to the listen mode of operation.
- **Full duplex voice systems** – The communication should be two-way simultaneously in real time, unless PTT is chosen mode of communication.
- **Dynamic Group Number Assignment –** It enables the creation of separate user groups and helps to improve the co-ordination between them. For example, police, fire and ambulance groups can be coordinated if the situation demands.
- **Direct Mode operation (DMO) or Talk around** – It provides unit-to-unit communication when out of range of the wireless network or in a confined area where it is desired.
- **Emergency Alerting Button –** It indicates that the user has encountered an emergency situation and requires an immediate access to the system and therefore, is given the highest priority. This feature activates an open microphone so that all that is audible is transmitted to the control Centre.

- **Audio Quality –** The listener must be able to understand without repetition and should identify the stress in the speaker's voice and also be able to hear the background sounds without interfering with the prime voice communications.

(v) Additional supplementary voice communication features required are: -

- **Talker Identification –** It provides the ability to identify the calling user device/handset ID at any given time. It is similar to Caller ID in commercial cellular systems.
- **Call forward when user busy/not reachable –** It allows the ability to forward the calls when subscriber is busy or out of service area.
- **Fast Dialing –** This service allows users to connect the individual calls quickly with short number dialing.
- **Late entry –** This service allows a user to connect at a later time to a group call. For example, if he/she was engaged at the time of the call or if he had not yet switched his equipment on.
- **Ambience Listening (called order-wire in traditional systems) –** A dispatcher may place a radio terminal in this mode without providing any indication to the radio terminal user. This remote controlled action allows the dispatcher to listen to background conversations within range of radio terminal's microphone. This feature is very useful during situations when the PPDR personnel are in danger (not able to even press Emergency Alerting button). The dispatcher must be an authorized person to operate this mode. Also as this service invades a person's privacy, hence only those users who need to be monitored under ambience listening as part of their work duties need to be identified with proper authorization as per the norms and should be provided with this service.

(vi) Key "mission-critical" data communication requirements for the PPDR communication network are:

- Capability to transmit both narrowband (messaging, etc) and broadband (images, video) along with location-based services (asset tracking, mapping, etc).

The following Table 1[1] provides gist of the PPDR specific features for each application in different frequency bands of operation.

Application	Feature
Narrowband	
Voice	Person-to-Person
	One-to-Many
	Talk-around/ Direct Mode operation
	Push-to-Talk

	Instantaneous access to voice path
	Security
Messages	Person-to-Person
	One-to-Many (Broadcasting)
Security	Priority/Instantaneous access
Telemetry	Location Status
	Sensory data
Database record (minimal record size)	Forms based records query
	Forms based incident reports
Wideband	
Messages	E-mail possibly with attachments
Data Talk-around/ Direct Mode operation	Direct unit-to-unit communication without additional infrastructure
Database interaction (medium record size)	Forms and records query
Text file transfer	Data transfer
Image transfer	Download/ Upload of compressed still images
Telemetry	Location status and sensory data
Security	Priority access
Video	Download/ Upload of compressed video
Interactive	Location Determination
Broadband	
Database Access	Intranet/ Internet access
	Web Browsing
Robotics control	Remote control of robotic devices
Video	Video streaming/ Live video feed
Image	High-resolution images

Table 1[1]: **- Different PPDR specific features required for different scenarios/applications**

2.4 Operational Requirements

Systems supporting PPDR should be able to operate in the various scenarios like day-to-day operations, large emergencies or public events and disasters. This section defines the operational requirements of PPDR users: -

2.4.1 Priority access requirements:

PPDR systems should have the ability to manage high-priority traffic and possibly manage low-priority traffic-load shedding during high-traffic situations. PPDR operations may require either the exclusive use of frequencies or equivalent high-priority access to other systems, or a combination thereof. In addition, this could also mean giving priority access to certain public safety personnel or agencies when they connect to a given network either permanently or at pre-defined times. This is especially important in any scenario where the network supports a mixture of PPDR communications and ordinary commercial communications. Priority access may entail some immediate pre-emption capability through the network (e.g. LTE priority access). One of the key requirements of the PPDR communications is the need to have dynamic priority management. These requirements may be deemed essential for providing mission critical PPDR operations.

2.4.2 Grade of service (GoS) requirements:

A suitable grade of service should be considered as a requirement that may be deemed essential for providing mission critical PPDR operations.

2.4.3 Quality of Service (QoS) requirements:

PPDR users may also require reduced response times for accessing the network and information directly at the scene of incident, including fast subscriber/network authentication.

2.4.4 Reliability requirements:

PPDR applications should be provided on a stable and resilient working platform. Reliability requirements should include a stable and easy-to-operate management system, offer resilient service delivery and a high level of availability (commonly achieved using redundancy and backup, fallback and auto-recovery, and self-organization).

In the event of a network failure or loss of network coverage, localized communication services such as isolated base stations, relayed device mode of operation, Direct Mode Operation (DMO) and Device-to-Device (D2D) communication are required between PPDR users as an immediate solution for re-establishing communications. Localized communication services are needed, either through deliberate user action or as a result of devices leaving the network coverage. Localized communications may also be required at a local incident where the coverage does not extend inside a building. These requirements may be deemed essential for providing mission critical PPDR operations.

2.4.5 Coverage and capacity requirements:

A PPDR system is typically required to provide extensive geographic coverage for "normal" traffic within the relevant jurisdiction and/or area of operation (national, provincial/state or local level). This coverage typically is required 24 hours per day, 365 days per year. To date, systems supporting PPDR agencies and organizations were designed for peak loads, and therefore experienced wide fluctuations in usage (including periods of minimal usage). Additional resources for systems providing for PPDR (e.g. enhancing either coverage, system capacity or both) may need to be employed during a Public Protection (PP) emergency or Disaster Relief (DR) event through techniques such as reconfiguration of networks with use of transportable base station sites, Direct Mode Operation (DMO), high-power UE and vehicular repeaters, and may be required for coverage of localized areas. Urban PPDR systems are often designed for highly reliable coverage of subscribers outdoors and indoors, using direct propagation through the walls of buildings. Sub-systems may be installed in specific buildings and/or structures like tunnels if coverage from external systems is insufficient.

Narrowband PPDR systems have tended to use larger radius cells and higher-power mobile and personal radios compared to devices available in commercial service providers' systems (for service to the general public). Trade-offs of coverage, capacity and spectrum reuse against infrastructure costs will likely be a decision for each administration to consider. Spectrum planning for narrow-band technologies such as TETRA, P25 and DMR provided sufficient channels within frequency tuning ranges and arrangements for DMO. DMO is also required on broadband systems, such as LTE when used for PPDR. As such, sufficient radio resources should be provided for its operation to cater for both cellular and direct mode communications. Use of DMO or D2D operation on broadband PPDR when smaller channel bandwidths are used, may place constraints on the number of supported user talks groups limited by the number of sub-carriers available per channel. Broadband PPDR systems typically employ a single wide frequency channel across the whole network. In order to address co-existence with other co-located D2D user groups and cellular services deployed in the adjacent channels, proper channel size planning should be considered.

2.4.6 Connectivity and compatibility requirements:

PPDR networks should allow end-user-to-end-user connectivity or otherwise be compatible with existing networks used for PPDR communications. Compatibility requirements may include diversity of supply, use of open international standards, backward compatibility and a smooth upgrade and evolution path. The current, on-going evolution of systems and technologies providing PPDR might alleviate most of the compatibility challenges.

2.4.7 Interoperability requirements:

Interoperability is an important requirement of PPDR operations. PPDR interoperability is the ability of PPDR personnel from one agency/organization to communicate and share data and multimedia in different management levels by radio with personnel from another agency/organization, on demand (planned and unplanned) and in real time. This includes the interoperability of equipment internationally and nationally for those agencies that require domestic and international cross-border cooperation with other PPDR agencies and organizations. Several options are available to facilitate communications interoperability between multiple agencies, networks and devices.

2.4.8 Security related requirements:

Efficient and reliable PPDR communications within a PPDR agency or organization and between various PPDR agencies and organizations, which are capable of secure operation, may be required. Notwithstanding, there may be occasions where administrations or organizations, which need secure communications, bring 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.

2.4.9 SDR (Software Defined Radio):

Enhanced functions for the user are possible with SDR technology that uses computer software to generate its operating parameters, particularly those involving waveforms and signal processing. This is currently in use by some government agencies. Some companies are also starting to benefit by using SDR technology in their products. SDR systems have the ability to span multiple frequency bands and multiple modes of operation and will have the capability in the future to adjust its operating parameters, or reconfigure themselves in response to changing environmental conditions. An SDR radio will be able to electronically “scan" the spectrum to determine if its current mode of operation will permit it to operate in a compatible fashion with both legacy systems and other SDRs on a particular frequency in a particular mode. SDR systems could be capable of transmitting voice, video, and data, and have the ability to incorporate cross-banding, which could allow for the ability to communicate, bridge, and route communications across dissimilar systems. Such systems could be remotely controlled and may be compatible with new products and backward-compatible with legacy systems. By building upon a common open architecture, these SDR systems will improve interoperability by providing the ability to share waveform software between radios – even those in different physical domains.

Further, SDR technology could facilitate public protection organizations to operate in a harsh electromagnetic environment, to not be readily detected by scanners, and to be protected from interference by a sophisticated criminal element. Additionally, such systems could replace a number of radios currently operating over a wide range of frequencies and allow interoperation with radios operating in disparate portions of that spectrum.

3. Current Technologies for PPDR communications:

The capabilities of various technologies for PPDR communications have been detailed below-

3.1 Technologies evaluated/recommended by ITU:

The following are the technologies for PPDR operations/communication recommended by ITU in its ITU-R Recommendation M.2009[7] and are in use across the world. The important features along with the technical parameters are discussed in detail for each technology, as follows: -

3.1.1 DMR (Digital Mobile Radio)

1) It is a digital standard developed for PMR (Professional/Private Mobile Radio) by ETSI
2) It operates in frequency bands of VHF (137-174MHz) and UHF (406-470MHz) bands.
3) Uses 12.5 KHz spaced carrier to send two TDMA slots.
4) Data rates up to 9.6 kbps can be achieved.
5) Latency time ranges around 100msec.
6) Coverage area is around 40km.
7) ETSI standard for DMR provides for 3 different tiers of radio communication systems:
    - **Tier-1:** These products were intended to operate in license-free European 446MHz band for an immediate change from the then existing Analog MPT 1327 (An industry standard by British Ministry of Post & Telegraph) systems. However, there had been no commercial launches of these products as on date.
    - **Tier-2:** These products are conventional radio systems, mobiles and hand portables operating in the above specified frequency bands. DMR Tier-2 products are available in the global market.
    - **Tier-3:** These products are trunked radio systems operating in the above specified frequency bands. It supports features similar to TETRA. Tier-3 compliant products were launched in 2012.
8) The DMR market is very limited as on date due to few equipment producers.
9) **India specific comments:** The products based on this technology can operate in earmarked 400MHz PPDR band in India. The frequency band of VHF (137-174MHz) is not allotted for PPDR in India.

3.1.2 TETRA (TErrestrial Trunked RAdio)

1) It is an open ETSI standard developed for digital PMR.

2) Initially termed as “Trans-European Trunked Radio” System. However, the system now being used beyond Europe, it was renamed as “Terrestrial Trunked Radio” systems.
3) It is operated in both 400 and 800MHz frequency bands.
4) Uses TDMA with carrier spacing of 25 KHz and four slots per carrier or traditional FDMA with 12.5 KHz carrier spacing.
5) Two versions of TETRA are TETRA Release1 and TETRA Release2 :-

TETRA Release1

(i) It was first published by ETSI in 1995.
(ii) Modulation technique used is Differential Quadrature Phase Shift Keying (DQPSK)
(iii) Data rates up to 7.2kbps per voice channel can be achieved and up to 28.8kbps also, if multi-slot operation is used.
(iv) Latency time is around 250msec.
(v) Practical cell radius achievable is 6 to 8kms. Theoretical (ideal) coverage range possible is 58kms.
(vi) In India, following are some of the agencies using TETRA Release1:
   - Military College of Telecommunication Engineering (MCTE) for Indian Army - in use since 2004 at Mhow, Indore, Madhya Pradesh.
   - Delhi Metro Rail Corporation Ltd for transport – First TETRA in India- in use since 2002.
   - Mumbai Mono rail, Mumbai Metropolitan Regional Authority for Mass transport (India’s first monorail project) - from 2010.
   - Kerala Police - TETRA with Automatic Dial 100 (AD100) - since 2008 in Trivandrum city.
   - TamilNadu police for Police and Internal Security safety - from 2011.
   - Delhi Government for Secure Communication network – since 2010 (used by various departments under Govt of Delhi and Delhi police).
   - Gas Authority of India Limited (GAIL) for Gas Pipeline-safety, Telemetry and security - from 2011.
   - Bangalore Metro Corporation Limited (BMRCL) for transport–since March 2011.
   - Gurgaon Police - TETRA with Automatic Dial 100 (AD100) - since 2009 (and since 2011 in Salem city).

TETRA Release 2 (an upgrade to TETRA Release 1)

(i) ETSI and TETRA Association at the end of 2005 develop it.
(ii) Following are the updates to the earlier version: -

- Trunked mode operation Range Extension to 83kms (exclusively Air-Ground-Air applications) from 58kms (theoretical) by modifying the uplink and downlink bursts and guard times.
- Use of Adaptive Multiple Rate (AMR) voice codec for a particular voice + data mode.
- Use of Mixed Excitation Linear Predictive enhanced (MELPe) voice Codec where military network interface is required.
- Introduction of TETRA Enhanced Data Services (TEDS)[8].
  - ✓ TEDS is fully backward compatible with TETRA Release1.
  - ✓ Data rates ranging from 15.6kbps to 269kbps can be achieved using scalable bandwidths and various modulation schemes (DQPSK, D8PSK, 4QAM, 16QAM, and 64QAM).
  - ✓ Coverage area is same as of TETRA release1.
  - ✓ Latency time is around 200msec.

3.1.3 APCO-25 (Association of Public-safety Communication Officials International-25) or P25 (Project25)

1) It is a suite of standards established in October 1989, standardized under the US Telecommunications Industry Association (TIA), and developed exclusively for Land Mobile Radios (LMR) for local, state/provincial and national public safety organization and agencies in North America.
2) It is equivalent to TETRA but both are not interoperable.
3) It operates in VHF (136-174MHz) and UHF (403-512MHz, 806-870MHz) bands.
4) Latency time ranges around 250msec.
5) Common Air Interface (CAI) standard is most widely deployed interface enabling interoperability between P25 radios and infrastructure irrespective of the manufacturer.
6) These radios can communicate in analog mode with non-P25 radios and in analog and digital mode with P25 radios.
7) Being deployed in several phases as follows:-
   - **Phase-1** operates in 12.5 KHz analog, digital or mixed mode using FDMA method. It provides 9.6kbps air link rate using Continuous 4-level FM (C4FM) or Continuous QPSK (CQPSK) modulation. Vendors are currently shipping Phase-I compliant systems.
   - **Phase-2** uses a 2 slot TDMA with 12.5 KHz bandwidth and 12kbps air link rate using Harmonized continuous phase modulation (H-CPM) and Harmonized Differential Quadrature Phase Shift Keying (H-DQPSK) schemes.

- **Phase-3** tried to address the need for high speed data for public-safety use. But due to lack of interest shown by the industries, this project was closed in 2010. Project MESA (Mobility for Emergency and Safety Applications), another name for this phase, is a collaborative working of ETSI and TIA.

8) Phase-2 of APCO-25 can be deployed in India in the above earmarked UHF band for PPDR operations.

3.2 Other technologies in use:

The following are the other technologies in use for PPDR communications in different parts of the world. The important features and parameters are discussed below -

3.2.1 TETRAPOL

1) It is a standard for digital cellular trunked radio systems developed by MATRA NORTEL communications in France, and later supported by TETRAPOL forum (predominantly manufacturers) and TETRAPOL users club (user organizations).
2) It operates in 400MHz and 800MHz bands with latency times ranging around 250msec.
3) Channel access method used is FDMA with Gaussian Minimum Shift Keying (GMSK).
4) TETRAPOL terminals operate in semi-duplex mode with one channel per carrier, where separation between carriers is 12.5 KHz.
5) Maximum data rate achieved is 7.2kbps (without encryption).
6) Theoretical cell radii that can be achieved is 28km. Practical achievable cell radii is 20km for rural areas and 6km for sub-urban areas.
7) In Switzerland, TETRAPOL digital trunked radio technology has been chosen for the new national emergency radio network, POLYCOM.
8) As it is a technology not standardized by international bodies and also being based on traditional FDMA access scheme, it might not be a better option suited for PPDR communications in Indian environment.

3.2.2 Amateur Radio (Ham Radio)

1) ITU through the International Telecommunication Regulations establishes the Amateur Radio Services whereas these Amateur Radios are represented and coordinated by the International Amateur Radio Union (IARU).
2) The two common modes used for voice transmission are Frequency Modulation (FM-provides high quality signals) and Single Side Band (SSB) modulation (used for long distance communication when bandwidth is restricted).

3) Amateur radios are often used to provide essential communication services when regular channels are unavailable due to disasters.
4) Amateur radio operators have to pass an examination conducted by the Ministry of Communications, Govt. of India to obtain the license for operating radio stations in India.
5) Amateur radios are already being used in India, now and then, during disasters.
6) Table 2 shows some of the frequency bands used for amateur radio services in India and their maximum transmitted power, maximum bandwidth and modes of operation.

Range	Wavelength	Frequency Band (MHz)	Max. Tx Power (W)	Modes of operation	Max Bandwidth (KHz)
MF	160 m	1.800-2.000	1500	CW, Data, SSB	3.0
HF	80/75 m	3.500-3.750	1500	CW, Data	0.2, 0.5, 3.0
	80/75 m	3.750-3.900	1500	SSB	3.0
	40 m	7.000-7.150	1500	CW, Data	0.2, 0.5, 3.0
	40 m	7.150-7.200	1500	SSB	3.0
VHF	2 m	144.000-144.100	200	CW, Data	100
	2 m	144.100-144.300	200	SSB	100
	2 m	144.300-144.500	200	Satellite	100
	2 m	145.800-146.000	200	Satellite	100
UHF	70cm	430.000-440.000	100	FM, SSB	100 (data), 6000 (VSB)
SHF	9 cm	3300-3500	1.0	Beacons	100 (data), 6000 (VSB)
	5 cm	5650-5850	1.0	Beacons	100 (data), 6000 (VSB)
EHF	4 mm	76000-81000	1.0	All modes	100 (data), 6000 (VSB)

Table 2: Table shows some of the frequency bands used for Amateur radio services in India and their maximum transmitted power, modes of operation and maximum bandwidth respectively

3.2.3 SATCOM (SATellite COMmunications)

Space technology has evolved into an invaluable asset in disaster management. Satellite communication channels often end up being the only mode of communication. e.g.:- Accurate advanced warning and tracking of cyclone Phailin saved countless lives recently. The LEO, MEO and GEO based satellite access systems are used for the purpose of PPDR.

The technical parameters are described below -

1) SATCOM systems operate in L (1 to 2GHz) and S (2 to 4GHz) bands. VSAT (Very Small Aperture Terminals) terminals in C (4 to 8GHz), X (8-12GHz), Ku (12 to 18GHz) and Ka (26 to 40GHz) bands are used for backhauling applications.
2) Main advantage is its use in remote and rural areas where terrestrial communication gets damaged or does not exist.
3) Interoperability is good in terms of PSTN connectivity but poor between different SATCOM providers and with other terrestrial networks like TETRA.

4) Network congestion for high number of users is a drawback since a large coverage is provided but with relatively few voice channels.
5) Lack of "Direct mode" capability is another drawback.
6) Latency is above 250msec for GEO satellites (due to large single-hop delay) whereas for LEO/MEO satellites, maximum delay is around 100msec.
7) Data bandwidths are also limited to maximum of 492 kbps on S-band. Nevertheless, higher data rates (upto 60 Mbps) can be achieved using next generation Ka-Band (26.5 to 40GHz) satellites such as Inmarsat's Global Xpress.
8) Transmission of real-time high-definition video (which is necessary for some scenarios) cannot be provided with SATCOM links.

Satellite phones:

In India, International Long Distance (ILD) license is required for operating the satellite-based mobile services, which requires a gateway to be established in India. Currently only Inmarsat services are permitted in India. No Objection Certificate (NOC) issued by DoT is mandatory for using satellite phones.

However, the major satellite phone systems in use around the world are-

1) **Iridium: -** This system uses 66 satellites orbiting in low earth orbit at an altitude of around 485miles above the earth's surface with an orbiting time of around 100mins. The satellites are able to communicate with the ground as well as neighboring satellites through inter-satellite links. This system uses 4 earth stations.
2) **Globalstar:-** This system uses 44 satellites rotating in orbits having an altitude of 878miles above the earth's surface with an orbiting time of around 2hrs. This system does not support inter-satellite links thereby not supporting hand-overs. It also cannot provide coverage where there are no earth stations.
3) **Inmarsat:-** It is the oldest satellite phone system founded in 1979. It originally provided large fixed installations for ships. It provides global coverage, except at polar regions, using eleven satellites.
4) **Thuraya:-** This system provides coverage in some areas within Africa, Europe, Asia, Australia and Middle East. It uses a single geostationary satellite and provides service through a network of service providers. Thuraya handsets support dual mode operation i.e in addition to supporting satellite networks, they can also connect to GSM900 networks.

4. Candidate technologies for PPDR in near future

The following candidate technologies are discussed below for PPDR in near future as they are in advanced stage incorporating required PPDR features by the standardization bodies:

4.1 Technologies evaluated/recommended by ITU

The following are the candidate technologies for PPDR communications/operations in the near future according to the ITU-R Recommendation M.2009[7]. The important features of each technology along with their technical parameters are explained below.

4.1.1 LTE (Long Term Evolution)

i) It was developed by 3GPP and first specified in Release 8.

ii) It is an all IP based network supporting both IPv4 and IPv6.

iii) The access methodology used is Orthogonal Frequency Division Multiple Access (OFDMA) for downlink and Single Carrier-FDMA (SC-FDMA) for uplink.

iv) Supported modulation schemes are QPSK, 16QAM, 64QAM for both uplink and downlink.

v) Provides peak downlink speed of 100Mbps (SISO), 172Mbps (2x2 MIMO), 326Mbps (4x4 MIMO) with 64QAM modulation scheme and peak uplink speeds of 50Mbps (QPSK), 57Mbps (16QAM), 86Mbps (64QAM).

vi) Both the duplex schemes (FDD and TDD) are supported with scalable bandwidths of 1.4, 3, 5, 10, 15, 20MHz per carrier.

vii) Supported mobility rates are up to 120kmph and latency time range around 10ms.

viii) Frequency bands used for LTE in Asia are 1800, 2100, 2300 and 2600MHz.

ix) In urban area to provide high-speed data, LTE is used at higher frequencies. Hence, coverage area per site would be typically around 1km or less. In general, lower frequencies are used in rural area making the coverage area extended up to 30kms (giving reasonable performance).

x) Prior to Rel-13, 3GPP standardized functionality that was later to serve as an enabler for MC Services. For example, MC Services benefit from the use of multicast bearers in LTE due to the standardization of eMBMS and Group Communication System Enablers (GCSE). Additionally, D2D Proximity Based Services (ProSe) was enhanced to support public safety use.

This allows public safety operators to determine whether critical communications occur on-network using the LTE network infrastructure, or off-network without the use of the LTE network infrastructure, or both.

4.2 Other candidate technologies:

4.2.1 Wi-Fi (Wireless Fidelity)

Wi-Fi can also be used as a candidate technology for providing data traffic distribution for PPDR communications. Its important technical features are discussed below -

i) It is a low cost, high efficiency network topology targeting local user communication.

ii) It is based on IEEE 802.11 standard and was first published in 1997.

iii) It is generally operated in unlicensed ISM (Industrial, Scientific and Medical) bands.

iv) The most popular standards are[11]:

- **802.11a:** Operates in 5GHz ISM band with data rates up to 54Mbps. Typical coverage range is 35mts (indoor) and 120mts (outdoor).
- **802.11b:** Operates in 2.4GHz ISM band with data rates up to 11Mbps. Typical coverage range is 35mts (indoor) and 140mts (outdoor)
- **802.11g:** Operates in 2.4GHz ISM band with data rates up to 54Mbps. Typical coverage range is 38mts (indoor) and 140mts (outdoor)
- **802.11n:** Operates in 2.4 and 5GHz ISM bands with data rates up to 600Mbps. Typical coverage range is 70mts (indoor) and 250mts (outdoor) which can be achieved in 2.4GHz band.
- **802.11ac:** Operates in 5GHz ISM band with data rates up to 3.47Gbps. Typical coverage range is 35mts (indoor).
- **802.11ad:** Wireless network bearer providing very high throughput at frequencies up to 60GHz.
- **802.11ah:-** Wi-Fi using unlicensed spectrum below 1 GHz to provide long-range communications and support for the Internet of Everything.

v) Modulation schemes used are Direct Sequence Spread Spectrum (DSSS), Frequency Hopped Spread Spectrum (FHSS), and Orthogonal Frequency Division Multiplexing (OFDM).

vi) Latency time is approximately 200msec.

vii) A high level of security is provided through encryption mechanisms like Wired Equivalent Privacy (WEP), Wi-Fi Protected Setup (WPS), Wi-Fi Protected Access encryption (WPA & WPA2), etc.

viii) Wi-Fi networks can be easily configured and deployed at the PPDR incident location where no other network is present.

ix) In addition, the integration of Wi-Fi networks is cost-effective as all the devices are of low cost and are readily available because the same Wi-Fi standard is being followed all over the world.
x) Major drawback of Wi-Fi w.r.t PPDR scenario is low coverage area.
xi) Security risks may arise if inadequately configured.
xii) As it is used in ISM band, there is always a problem of the network being interfered by other devices such as microwave ovens, security cameras, cordless phones, etc, which might lead to lowering of speed or even to the disruption of the connection.
xiii) In addition, the data speed depends on the mobility (high/low), distance from the access point and the number of users competing for access.

4.2.2 LTE -Advanced

4G (LTE-A) is a mobile network technology standardized by 3GPP Releases 10, 11 and 12 meeting the 4G requirements defined by ITU. This technology includes a large number of improvements and new content when compared to 3G and early LTE, some essential ones being-

- Significantly improved bandwidth, with data transfer bit rates up to 1 Gb/s
- Shorter round trip delays (RTT) giving more responsive systems
- Carrier aggregation enabling frequency band combining to make more bandwidth available for users
- improved quality of service (QoS) control mechanisms
- simplified network architecture, leading to lower implementation costs for mobile network operators

LTE-Advanced systems (Release 13 onwards) have attractive capabilities of meeting the needs of broadband PPDR. LTE-Advanced can meet the needs of mission critical intelligence by supporting mission critical voice, data, and video services as an IMT radio interface.

LTE-A supports several functionalities needed for Public Safety, most important one being the Mission Critical Push-to-Talk (MCPTT) voice service in Rel-13, completed in 2016. To provide organizational support and focus a new working group - SA6 - was established in order to complete the new application related work in concert with other 3GPP working groups. MCPTT was the first major step in a series of MC Services and functionalities demanded by the market. In Rel-14, completed in 2017, 3GPP added additional MC Services and enhancements to its repertoire of standardized applications, specifically:

- Enhancements to MCPTT

- MCData
- MCVideo
- General framework which facilitates standardizing additional MC Services

The Rel-14 work on MC Services required not only a large set of new protocol additions and new security functionality, but also enhancements to the MCPTT Rel-13 specifications to enable reuse of common functionality across MC Services. The MC Services introduced in Rel-14 offer stand-alone functionality that enriches the existing base of MC Services. The set of features included was carefully chosen so that implementers need not have to wait for the completion of additional standardized functionality in Rel-15. The Rel-14 MCVideo and MCData specifications therefore offer equipment vendors as well as network operators a consistent and fully specified set of standards, ready for initial implementation and deployment.

LTE networks will need to meet the stringent requirements of mission critical communication for coverage, availability and security in order to be applied for operational use in Public Safety organizations.

4.2.3 5G (5th Generation):

The 5G (5th Generation) as a technology is being standardized by 3GPP through its Releases 15-16 onwards. The key requirement of 5G is to address market verticals such as automobile industry, IoT, industrial solutions and mission critical (MC) communications. 3GPP working on Rel-15, the first release of the 5G system. In Rel-15, the MC Services are further evolved. In addition, 3GPP is also working on service requirements for Rel-16, the second release of the 5G system. Releases 15 and 16 are expected to be finalized soon, and trials as well as deployments are expected to start by 2019-2020. The following are the key requirements in 5G relevant for Public Safety:

(i) Reliability and security:

High availability and reliability are key requirements of public safety. When a police officer is in a dangerous situation, he/she must be able to rely on the radio device. Radio coverage needs to be widespread and communication immediately activated when the officer pushes the button on the device. Uncompromised security is also a must for Public Safety users.

5G will provide several new technologies which improve the reliability, availability and security of communications. These include Device-to-Device (D2D) communication, user- and control plane separation by using Software Defined Networking (SDN) and

Multi-Access Edge Computing (MEC). Flexible use of radio resources with the Multi-Connectivity technology also contributes to improved reliability.

(ii) Traffic prioritization:

Critical communications networks need to be designed for the very worst cases. The dimensioning of the network capacity should be based on situations where large numbers of people are in a small area and the network load is peaking simultaneously. Typically, when first responders need to have the most capacity, for example at big events or major accidents, people around them also want to communicate. If using the same network, priorities must allow the necessary capacity and performance for first responders. This includes the ability to ruthlessly pre-empt some users' services in order to provide immediate services for first responders in emergency or perilous situations.

5G will add new technologies to the existing ones, which enable different use cases with different requirements in one physical network. With Network Slicing technology, a single network can be divided into several virtual networks with different use cases and priorities. This opens new business opportunities for infrastructure sharing for different niche operators, including Public Safety. Separating user- and control plane traffic with SDN and NFV (Network Function Virtualization) technologies are key for managing dynamically changing capacity needs in the network.

(iii) Sensors and Internet of Things:

The IoT is one of the key drivers of 5G. The target is to support very large number of machines that can communicate with each other, exchange data and automate processes. New requirements include ultra-low cost devices, a long battery life and properly managed network capacity, even with a very large number of devices. Sensors and machines can also be very critical, for example industrial solutions or autonomous cars. This calls for very low latency and highly reliable communication.

In the future, sensors, cameras and other automated devices will be a significant source of information for the Public Safety community, complementing conventional sources such as police officers in the field. Information from citizens about incidents will also become increasingly important for building a full picture.

By integrating all this information into Public Safety operations, first responders can be less reactive and more proactive – for example moving from the investigation of crimes towards the prevention of crimes.

4.3 Applying 4G and 5G for Public Safety

Every country has its own requirements and plans in relation to the implementation of a next generation Public Safety communication solution. These plans depend on multiple national drivers including national security policy, financial situation, life-cycle phase of the current deployed narrowband solution and mobile network operators' interest/capability to offer mission critical service.

In case of urgent needs, 4G usage can be started quickly, but will probably not support all the capabilities and features of current PMR systems. One easy way to start would be to use broadband data services with an MVNO arrangement, which is improving service availability and security. Adding national roaming with all operators will increase the coverage and availability further. Standard compliant 4G based PTT voice service could be started as soon as implementations from equipment providers are proven, trialed properly by Public Safety users and mature enough for operational use.

4G forms a good basis for Public Safety implementations. However, this naturally requires that Public Safety fit for purpose functionalities are implemented by network equipment vendors, tested across multiple vendors' solutions and trialed properly with Public Safety users.

A 5G implementation will also include all 4G functionality and all required Public Safety services will be available. However, the idea of waiting for the next technology level or 3GPP Release because it is offering better service for Public Safety can easily trigger an everlasting waiting loop while the next technology level is always offering something more and better than the previous one. Deploying 4G will also give additional experiences for the use cases that are most needed and can improve 3GPP standards more quickly. In addition to this, deploying 4G would also enable users to start learning characteristics of the new solution.

Improved air interface performance (extreme Mobile Broadband and new radio interface) is completely new content within 5G but the improvements in 4G (on which 5G is based) is ongoing. However, new radio interface aimed at supporting very high frequencies i.e. very small cells, and all related Public Safety use cases have not yet been identified.

The ecosystem changes from the narrowband PMR ecosystem to 3GPP ecosystem is a big step and it is a challenge for the Public Safety community to operate properly within this environment. This is time consuming, and learning the new environment can be done only with efforts related to Public Safety service implementation and operational use of implemented solutions.

4.4 Future of existing technologies in PPDR:

PPDR communications would like to benefit from the existing evolution in mobile technologies to use broadband services. One can envisage that future PPDR networks will be based on LTE (LTE-Advanced) technology but existing narrowband networks (e.g. TETRA) will still be required due to their maturity and proven provision of mission critical voice communications. Nevertheless, LTE technology has to be significantly developed in order to meet the requirements of Public safety organizations and work is currently ongoing within the 3rd Generation Partnership Project (3GPP) as well as by TETRA and Critical Communications Association (TCCA). The main benefit from the deployment of LTE broadband networks is the provision of video. One of the crucial aspects of the migration path is selecting a business model that meets the requirements of a broadband network defined by the PPDR organizations. Also the re-allocation of the spectrum may take several years and will vary by country. Therefore, the process of evolution towards broadband networks will certainly take a few years.

5. Possible deployment scenarios (technological solutions) for deployment in PPDR operations

Technologies explained in the previous section are standalone access nodes/systems. However, one or more technologies may be required to be used in combination. Hence, several technological solutions have been discussed/proposed under various subsections as follows: -

5.1 Compact/ single spot deployment system/solutions especially for DR operations: -

The system may need the generic requirements specific to single spot/ localized Disaster Relief communications: -

(i) To meet the requirements of the emergency situations, the system need to be portable, customizable and deployable quickly, as well as compatible & capable of establishing secure connection with the operational/command and control center for all contingency communications, in a short duration.

(ii) The system need to become operational within a short time (say in few minutes) after powering on and need to be fully pre-configurable with the desired number of handsets, each allotted with an individual extension number**.**

(iii) The system need to consume less power and be able to work on battery (like lithium) with typical backup for 8 to 10hrs; and also need to support working on 230V AC power supply including battery charging. If the battery charge goes down, then it need to shut down ensuring that all the components follow the correct closure procedure thus eliminating problems of re-initialization.

(iv) The system need to have PTT functionality for group activities, with the option of an overlay applications platform to further improve its utility. These applications may include recording and storage of calls, search and retrieval of recorded calls, web interfacing through IT equipment and servers, etc.

(v) The system must be interoperable & must support variety of interface/ options to be able to integrate into the commercial public network as well as into the secured government communication network, if any available in place.

(vi) The system need to be compact for easy transportation, and need to be self-contained and rugged, to survive harshest weather conditions in the disaster environment.

(vii) The system need to be capable of providing integrated voice/video/data services with satellite/microwave link/fiber backhaul, even in the most remote and challenging locations.

(viii) It may also have a provision to increase the range of network coverage of such system through satellite, WiMAX or other backhaul methods.

(ix) Once the emergency situation comes under control, it is desirable that the same system may be used to extend community services (like locating people and resources) until the conventional wire line or public mobile network services are restored to normal conditions. In such case, it may also need to provide all major functions of a commercial network.

5.1.1 Portable GSM Mobile Networks (PGMN)

Considering the wide coverage spread, easy availability and cost advantages, the GSM can also be explored for use in countries like India for Disaster Relief operations.

The recent developments in this field have resulted into introduction of portable and easily deployable GSM product during emergencies. One such kind of product is Portable GSM Mobile Network (PGMN). This product is available in the market in the name of Rapid Deployment Unit (RDU). The TEC GR (Generic Requirements) numbered GR/WS/BSS-002/01.DEC2009 provides for small size GSM radio subsystems which includes its applications for Disaster Management.

PGMN is an integrated GSM network that provides the ability to access integrated voice and data services using existing 2G and 2.5G handsets over private GSM network. The readily deployable portable GSM unit is preconfigured with a required number of handsets, each having an individual extension number. This unit provides temporary telephony service to the pre-defined handsets until the normal condition is restored in macro network which either got congested/choked due to sheer volume of cellular traffic at the scene/destroyed or crashed in the disaster thus severely restricting the communications.

The unit allows the transmission and reception of calls over GSM by utilizing an integrated GSM Base Transceiver Station (BTS). It works in conjunction with a Mobile exchange software platform containing the individual software components that would make a macro network i.e a Base Station Controller (BSC) and a Mobile Switching Centre (MSC), which incorporates an SMS switching centre. The unit also has a laptop where all the technology related to software components used is pre-installed. This unit has an internal battery life of around 10 hours. It supports 230V AC power source as well as solar power to power the unit.

It supports lesser capacity (fewer terminals) compared to the normal network and provides coverage area around 900mts (outdoor). Also existing 2G and 2.5G handsets at the disaster affected/targeted area can be used, if needed. This unit has an Ethernet connectivity to connect to the fixed IP backhaul such as IP Broadband or VPN, wherever available. Also it can be integrated into a specialist vehicle such as COWs (Cell on Wheels), COLTs (Cell on Light Trucks), as shown in Fig 1, which have a provision for satellite or portable microwave backhauling to connect to the control center.

Source: www.deadzones.com

Fig 1: Cell on Wheels (COW)

Push-to-Talk feature is not available in this system at present, thereby not allowing group calling. Also it cannot support high speed video transmissions as this unit supports up to GPRS (2.5G) technology (thereby restricting the speed to 114kbps).

5.1.2 Portable TETRA network

As TETRA is one of the commonly used technologies for PPDR services, it would be a better option if it is made portable and easily deployable in the emergency areas. The readily deployable and portable TETRA unit has all the features of the macro network and can provide secure communication between the terminals. It provides higher coverage area compared to DMO of the TETRA terminals. By deploying this system, one can work in enclosed spaces also without any disruption in signal. A mobile van such as COWs, COLTs, as shown in Fig 1, can be used for bringing the portable TETRA equipment to the targeted area. Also RATs (Remote Antenna Trailers) can be used as a back-up antenna service. A satellite or microwave backhaul link may also be provided to operate efficiently even in remote locations.

A model of Portable TETRA with satellite backhauling is shown in Fig 2.

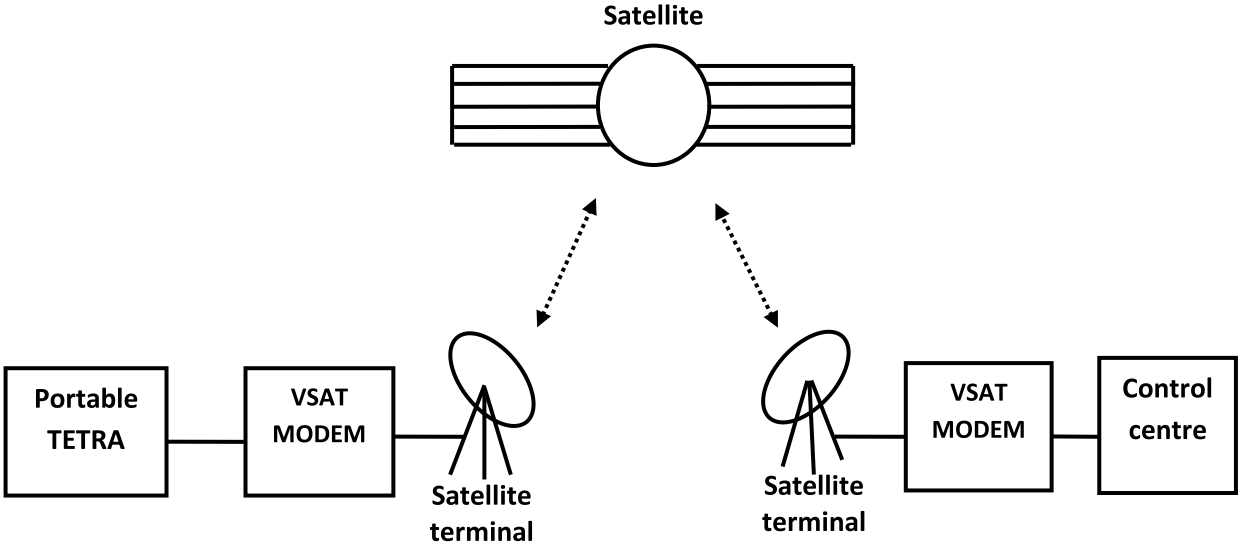

Fig 2: Portable TETRA system with VSAT backhauling

This solution works similar to that of PGMN solution (discussed above), but giving an add-on advantage of security and additional features such as PTT, DMO, emergency alert, etc. Being smaller in size, the transmitted power would be less compared to macro TETRA network thereby supporting only fewer terminals (capacity supported is less). Besides this, all the features achieved through macro network can be obtained through this network.

5.2 Possible technology solutions, subject to certain modifications/ facilitations:

The solutions proposed in this subsection can be implemented after making certain modifications/ system integrations, depending on the technical feasibility/compatibility.

5.2.1 Master-Slave configuration in TETRA networks:

TETRA is widely used in Europe and also in India as one of the main PPDR technologies. However, in TETRA networks, when the terminals are outside the range of the coverage area or if the network gets destroyed in a natural calamity, they cannot use the system infrastructure and will switch over to the DMO mode. In this mode, only simplex communication is possible making itself restricted to one-way individual calling whereas half-duplex group calling is a desirable solution during most of the emergencies. Hence to overcome such problem, one can go to a master-slave configuration.

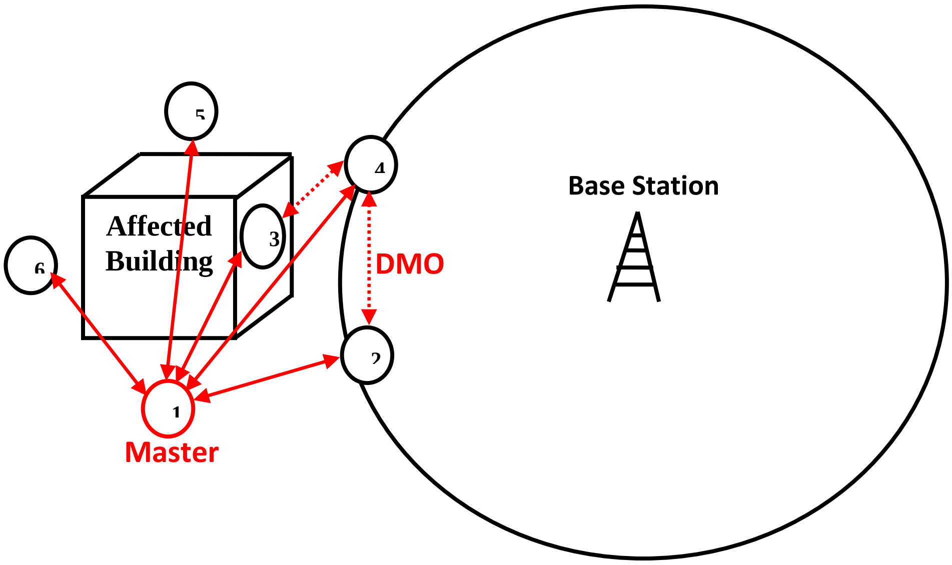

Fig 3: Figure portrays the Master-Slave configuration formed between the terminals

Figure 3 illustrates such configuration. In this figure, terminals 1, 3, 5 and 6 are out of the range of the base station. Terminals 2 and 4 also cannot receive the signal if the network gets destroyed during a natural calamity. Here the terminals are software preconfigured in such a way that one among them would act as a Master (virtual control station) thereby routing the signals between the other terminals (slave), thus creating a mini-TETRA network. The software configuration need to be done in such a way that the Master shall be able to handle minimal voice and data requirements required for effective communication between the terminals. The personnel handling the Master terminal requires to be trained before-hand to avoid instrument mishandling problems.

This can be an additional PPDR feature that can be implemented in the TETRA terminals thereby providing an added advantage over DMO operation. However, there are no standards available as on date on this feature.

5.3 Possible solutions that may be feasible in near future

The solutions proposed in this subsection can be implemented in the near future after standardization of constituent subsystems, wherever required. Also some of these solutions need certain PPDR specific standards to be developed for its successful implementation for PPDR operations in India.

5.3.1 S-UMTS (Satellite-Universal Mobile Telecommunication System) in conjunction with T-UMTS

A. S-UMTS stands for the satellite component of the UMTS system. S-UMTS is based on 3GPP specifications, complements the terrestrial UMTS (T-UMTS), and interworks with the other IMT-2000 family members through the UMTS core network. It delivers 3rd generation mobile satellite services (MSS) utilizing either LEO or MEO or GEO systems.

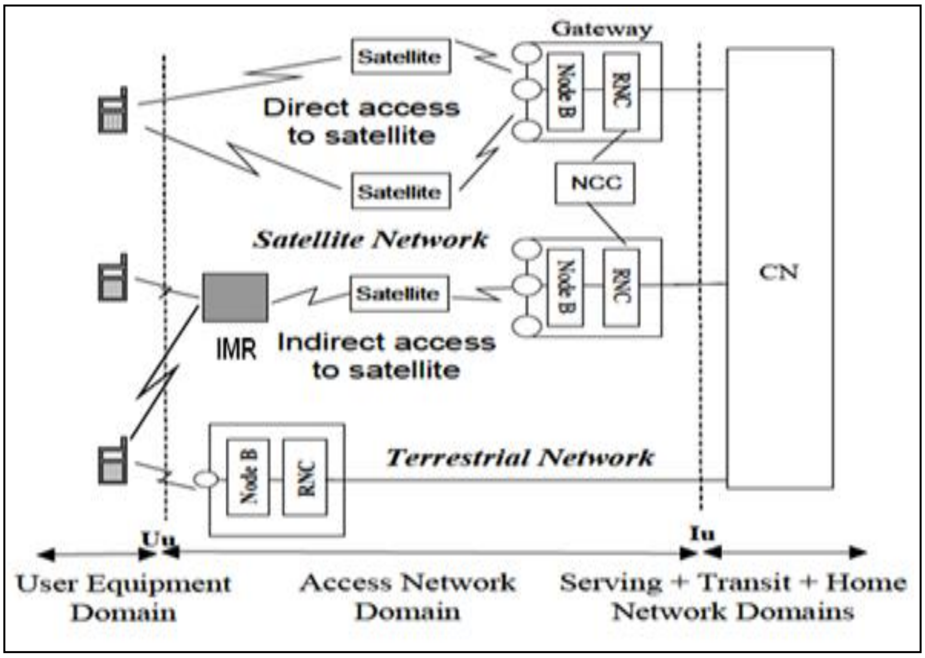

Fig 4: S-UMTS architecture

B. Fig 4 shows the basic S-UMTS architecture and its internal subsystems required for communication. In the first mode, the access to satellite communications is made possible using satellite phones, which operate in the particular frequency range. In the second mode, the access to satellite communications is made in an indirect way by using the existing terrestrial terminals. This indirect access to the satellite is made possible through IMR (Intermediate Module Repeater). The figure clearly explains the advantage of IMR in PPDR scenarios where the terminals can access the regular terrestrial network or the satellite through IMR, as the case may be. Thus, S-UMTS systems would be of real use during disasters in providing high data rates without any signal disruption.

C. The satellite services could be provided either using LEO/MEO or GEO constellations. A large number of LEO/MEO satellites are usually required for global coverage whereas 4 GEO satellites are required to guarantee global coverage. Typical delay for GEO satellites is 240msec compared to 5 to 20msec for LEO and 70 to 100msec for MEO. Hence, GEO is comparatively less suitable for applications requiring low delay (in case of PPDR applications like real-time video). In any case, if much inherent delay is acceptable to the user agency, it offers a useful solution.

D. Here in this system, another drawback is that current UMTS network terminals do not have PPDR specific features like Push-to-Talk, DMO, etc. In addition, they may suffer from network congestion if more number of PPDR users use those limited channels. Hence, this solution would be of greater use if terminals supporting all the required features were developed. However, the solution provides sufficiently higher speeds with global coverage.

5.3.2 TETRA + LTE

A. Even though voice being the basic communication requirement for PPDR, need for broadband data transmission during emergency scenarios such as high quality pictures of affected areas, live videos, etc have led to the search for new technologies which could meet all such needs. Also from the discussion above on the technologies, it can be observed that LTE would satisfy all the broadband requirements needed to meet the demands. However, it may have to still rely on conventional PPDR technologies such as TETRA for secured, clear and instant voice communications.

B. LTE might be a best option in providing high data rates but not able to meet all the PPDR specific requirements at present. Hence, an integration of TETRA and LTE can be considered as a better option for catering to all the demands. For this to happen, the first step is to upgrade the TETRA network to an all IP based network so that it can integrate well with the LTE. As both being two different standards, an Inter-System Interface (ISI) need to be developed between the two systems so that single user subscription can be used for both thereby eliminating the use of two different terminals.

C. Meanwhile, TETRA Critical Communications Association (TCCA) signed a 3GPP Partnership Agreement[13] on 31st October, 2013, declaring it as a partner with 3GPP. The TCCA Critical Communications Broadband Group (CCBG), which is working to guide the critical communication community towards a "commitment to a common mobile broadband technology solution-based on LTE", is also working closely with 3GPP on Spectrum, Architecture, User Requirements and on strategic case studies. The aim of the CCBG is to enable all mission critical and business critical users to access their information systems, intranet and internet at broadband speeds using their professional mobile devices wherever they are and whenever they have the need. This broadband capability should meet the specific needs of the user in the same way that critical voice and narrowband data services are currently delivered by technologies such as TETRA, Tetrapol, P25 and others.

D. The broadband LTE can be deployed in the following ways:-

(i) **LTE service from standard commercial networks: -**

It is the simplest and cheapest option of using the LTE services. The main advantage is low CAPEX and nominal OPEX costs. The disadvantage can be that the coverage, availability and resilience offered by the commercial networks may not be up to the desired level in all the situations. In addition, the network congestion during emergencies may lead to serious problems. This option can be considered for non-critical data-only service requirements.

(ii) **LTE service from commercially owned dedicated networks: -**

Here commercial operators provide the LTE services but these LTE networks work exclusively for PPDR operations. These networks can meet the required coverage and availability requirements of PPDR and help to give priority access to the PPDR users thus eliminating network congestion problem. In addition, some of the network elements such as backhaul can be shared with the commercial operators thereby reducing the infrastructure costs.

(iii)**Using own LTE dedicated network: -**

In this case, the PPDR users build, own and operate their dedicated LTE network. This involves higher CAPEX and OPEX costs compared to above-mentioned models. However, as it is completely owned and used for the PPDR requirements, all the PPDR specific requirements can be met.

(iv)**Hybrid Approach: -**

As none of the above approaches was found to be completely advantageous, a hybrid approach can be used. In this approach, dedicated networks can be deployed to fill the coverage gaps formed between the areas covered by the commercial networks. Also this approach can be used by deploying dedicated networks where high traffic is prevalent while using commercial networks in occasional traffic areas. This reduces the CAPEX and OPEX costs compared to owned dedicated networks. However, there are a number of issues involved in this approach that need to be sorted out at policy level such as interoperability of equipments and interconnectivity with different operator networks, etc.

E. Integration of TETRA and LTE for PPDR operations can be done in the following possible deployment scenarios, subject to development of suitable standards for NIS and ISI (indicated in fig 7) in due course of time: -

Here we assume that TETRA is already deployed and LTE deployment can be done on top of it as follows: -

- **Deploying LTE only in hotspots: -**

Here LTE is deployed only in most probable disaster-prone areas (hotspots), in addition to using TETRA in the normal way.

Figure 5 represents an overview of such system. Here hot spot areas include command and control centers, earthquake prone areas, coastal areas, etc. Here the TETRA takes care of the voice and low data rate applications like GPS positioning for AVLS (Automatic Vehicle Location System) whereas LTE deployed in hot spots takes care of the broadband demand required.

For this kind of deployment, LTE services from the dedicated network may be used as they would support all the specific requirements of PPDR with less CAPEX (for self-owned) and moderate OPEX (for commercially owned) costs as less number of LTE BTS are required.

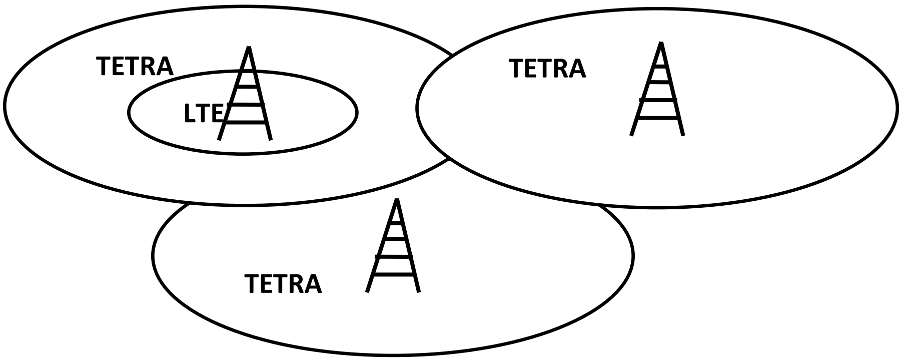

Fig 5: Overview of LTE (hotspot) system

- **Deploying LTE everywhere: -**

Here LTE network is deployed everywhere (similar to TETRA networks). These generally include locations such as police stations, check posts, hospitals, etc along with hot spots. Figure 6 represents the overview of such system. Here also, TETRA provides the secured voice services and minimum data services like GPS positioning for Automated Vehicle Location System (AVLS) and LTE provides the broadband data services.

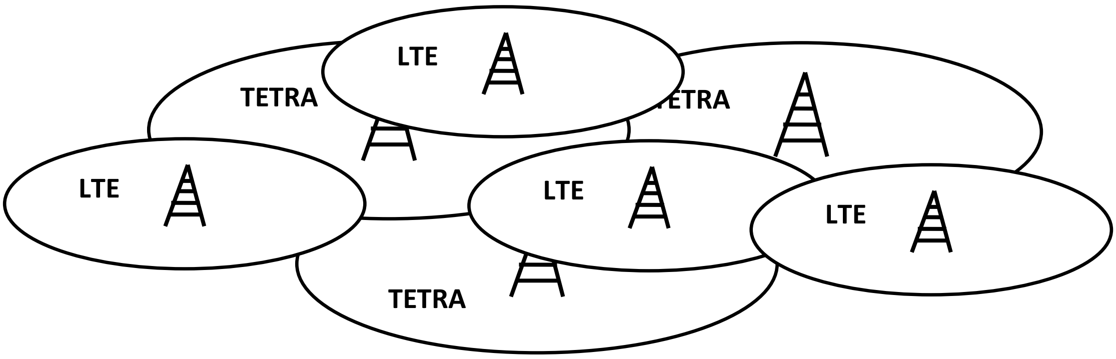

Fig 6: Overview of LTE (everywhere) system

For this kind of deployment, commercial networks may be used thereby avoiding high CAPEX costs (as more LTE BTS are required). In addition, hybrid approach may be used if coverage and availability of the network is a major requirement.

F. Figure 7 illustrates the system architecture of TETRA+LTE systems. In the proposed architecture, at the terminal end, both the systems (TETRA and LTE) work independently and get interfaced using Inter System Interface (ISI) i.e. voice flows through TETRA and data flows through LTE from the terminals through ISI. At the back end, the interfacing between the two system infrastructures to the control room is done using Network Interfacing System (NIS). Thus the voice services are routed through the TETRA systems and thereby to the TETRA infrastructure from which it passes to the control room through NIS i.e. after being interfaced with the data (wideband/broadband) flowing through the LTE infrastructure.

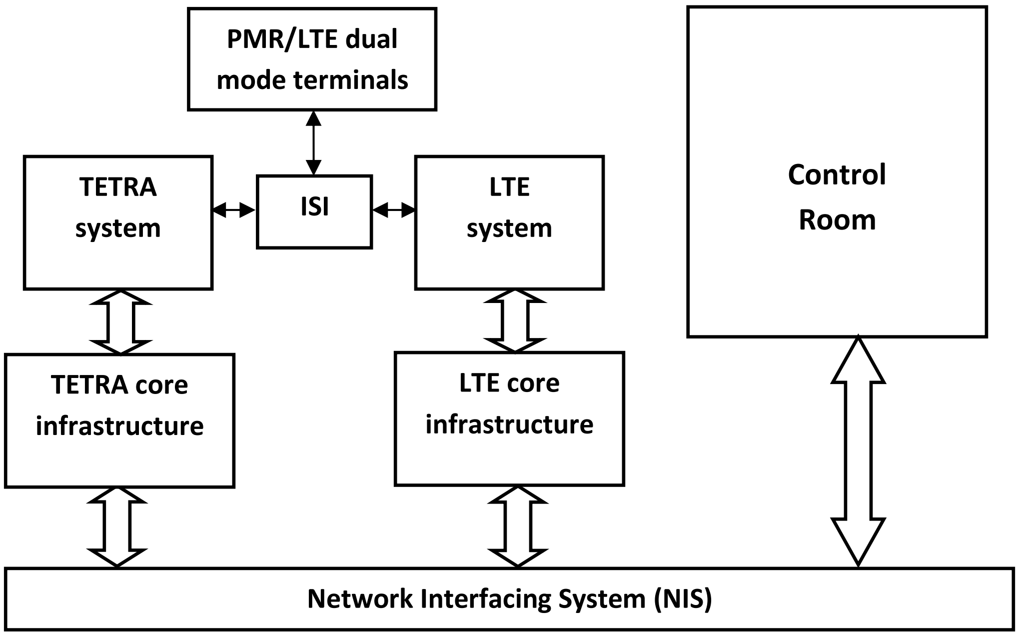

Fig 7: Proposed system architecture of TETRA+LTE systems

The above-proposed system coupled with Ku-band or Ka-band VSAT backhauling can make a complete solution for PPDR operations.

G. In the above configurations, if TETRA already exists, the same can be used for secured voice communications. Otherwise, an IMS based solution with VoLTE (Voice over LTE) can be deployed.

5.3.3 Pure LTE network

A. The above discussed solution integrates both TETRA and LTE to cater all the broadband demands in addition to voice services. This can be used as an intermediate step before migrating to pure LTE network as it has to incorporate several PPDR specific features like DMO (Pro-Se), Group calling feature, emergency alert, etc. All these features are covered in Release 12 and subsequent series of 3GPP. As the LTE has grown into a full-fledged PPDR network, it alone can be used to meet all the requirements.

B. As it operates at higher frequencies, coverage range would be less requiring more number of BTS to be deployed thereby increasing the costs. If 700 MHz band is used by LTE (which is used in countries like USA), then it can cover almost same area as of TETRA thereby reducing the infrastructure costs.

C. Most of the new in-demand services of PPDR applications are data-centric which can be met through the basic IP connectivity service provided by LTE. In addition to LTE, standardized commercial technologies (such as IMS) and a number of service enablers specified by Open Mobile Alliance (OMA) can be leveraged to provide IP based multimedia services to PPDR users. One of the IMS based solution is Voice over LTE (VoLTE). Also OMA's Push-to-talk over Cellular (PoC) can also be adopted to enrich all PPDR specific features into LTE.

D. Figure 8 represents the overview of complete LTE network system. Hybrid approach may be well-suited for this kind of deployment.

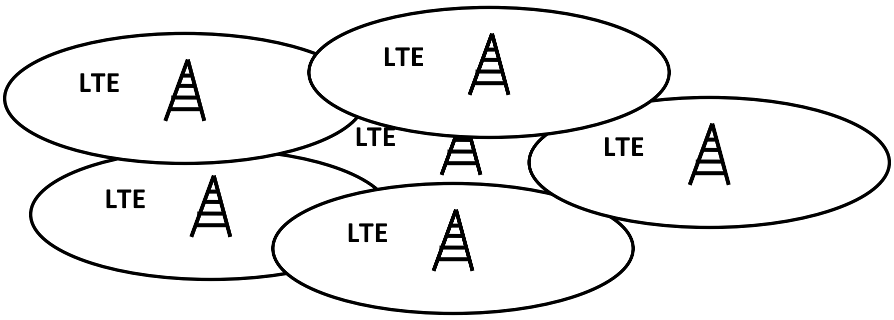

Fig 8: Overview of LTE (complete) system

E. Thus, a complete LTE system can be a stand-alone solution to cater to all PPDR demands. But it might take quite some time (around 5 to 10 years) to achieve this, as current LTE system is not capable of providing all the PPDR specific features required to tackle emergency situations (Release 12 might give a complete picture of LTE suitability for PPDR services).

F. To backhaul such a large data rate supporting system during disaster scenarios, a high bandwidth supported Ku or Ka band VSAT system may be required.

5.4 Possible solutions subject to availability of standards/products in future

The solutions proposed in this subsection are technically feasible subject to availability of standards and further research/standardizations.

Integrated TETRA and SATCOM

Natural disasters cause failure of terrestrial networks such as TETRA causing failure of PPDR communications. In such situations, satellite communications are the only source on which PPDR users can rely on. Satellite systems provide global coverage using satellite constellations thereby allowing continuous network availability at any point of time. Hence having an integrated TETRA and SATCOM systems can always be a useful option for the PPDR users during emergencies. Thus Dual Mode Radio Terminals (DMRT) which can support both TETRA and SATCOM need to be standardized and developed for this purpose.

Integration of two technologies can be done in two ways:

1) **Option-1: -** Here integration is done in such a way that the DMRT always gives first priority to the TETRA network. If the receiving signal or the network availability is less, then it automatically gets switched over to the satellite network. This kind of system will have higher initial set-up time as it needs to decide about the switch-over of the networks, thereby requiring extra switching elements. In this, DMRT uses only one network at a time (after the switching decision is taken). Here it can use both voice and data services simultaneously (even if one network fails during disaster) but at the cost of accepting their drawbacks (for example, TETRA can provide secure transmission but at low data rates whereas SATCOM can provide higher data rates but may suffer from network congestion problem).

2) **Option-2: -** In this, DMRT shares the services between TETRA and satellite networks i.e. voice services are always routed through TETRA networks and data services are always routed through satellite networks (As SATCOM supports higher data rates and TETRA could offer secured voice communication). Here, initial set-up time is less compared to option-1 (as no switching decision is required). Also if one network fails, then it can provide either only voice or data service but not both. PPDR users can enjoy all the advantages provided by both the networks i.e security and DMO advantages of TETRA along with higher data rates and wide coverage provided by SATCOM.

6. Conclusions:

The important outcomes of this study paper are as follows: -

(i) The technologies currently existing for PPDR operations in different countries are DMR, TETRA, TEDS, TETRAPOL, APCO-25, Amateur Radio and SATCOM. The technologies which have the potential to meet the broadband requirements for PPDR are LTE-A, Wi-Fi, and 5G.

(ii) No single technology can fully meet the present day PPDR requirements and hence combination of technologies may have to be deployed. Based on this conclusion, possibility of several technological solutions has been discussed and certain proposals have been made in this paper to cater to the present and future PPDR requirements.

(iii) The suitability of the solutions proposed in this paper need to be assessed before being deployed, as a single technological solution might not be suited for all kinds of situations especially for countries like India which is vast and has varied geography.

(iv) In India, different PPDR agencies are using different technologies. This might lead to a serious interoperability problem when inter-state (or inter-agency) co-operation is required for some incidents. Addressing these issues, a suitable policy may be devised for its successful implementation throughout the country.

(v) LTE is transforming into a complete PPDR technology. Most of the North American and European countries are also moving in this direction to standardize their PPDR networks. In the event of LTE becoming full-fledged PPDR technology in India, there may be options of using public network or setting up dedicated network owned and operated by state agencies. Keeping in view techno-economic factors, mixed approach may be needed.

(vi) The frequency bands of Wi-Fi (additional frequency bands) need to be identified and some chunks earmarked exclusively for PPDR operations in NFAP as the already existing bands are being widely used and also to avoid interference due to other ISM band devices/Wi-Fi networks.

(vii) To develop/build products corresponding to the proposed solutions in India, contribution is needed from the R&D units of telecom such as C-DOT.

(viii) NDMA in its document on "Guidelines for National Disaster Management Information and Communication System16" has planned a National Disaster Communication network (NDCN) which is expected to be a reliable, dedicated and latest-technology based communication network. The study of technological solutions mentioned in this paper is expected to be helpful while implementing the proposed network. The proposed NDCN of NDMA envisages its connectivity with the public/commercial network. Therefore, there is a need for NDMA to work out the network architecture in co-ordination with DoT/TEC in order to address the interoperability issues that may arise due to interconnectivity required with different service providers.

(ix) As a permanent measure, there should be a centralized core telecom network connected to all operators' core networks to provide traffic routing from public networks and PPDR networks to respective control and command centers of NDMA/other agencies. Such a core network need to be owned by the Government (DoT), keeping in view the multi-stake holder/multi-operator environment in which it has to operate. NDMA can easily ride upon such a network with ease of operation from any part of the country.

Abbreviations

3GPP	3rd Generation Partnership Project
APCO25	Association of Public-safety Communication Officials International-25
CAPEX	Capital Expenditure
CMRTS	Captive Mobile Radio Trunking service
COLTS	Cell on Light Trucks
COWS	Cell on Wheels
D2D	Device to Device
DeitY	Department of Electronics and Information Technology
DMO	Direct Mode Operation
DMR	Digital Mobile Radio
eMBMS	Evolved Multimedia Broadcast Multicast Services
ETSI	European Telecommunications Standard Institute
GIS	Geographic Information System
GSM	Global System for Mobile communications
ICT	Information & Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IMS	Internet protocol Multimedia Services
IP	Internet Protocol
IT	Information Technology
ITU	International Telecommunication Union
LCS	Localized Communication Services
LEO/MEO	Low/Medium Earth Orbit
MC	Mission Critical
MEC	Multi-access Edge Computing
MESA	Mobility for Emergency and Safety Applications
MHA	Ministry of Home Affairs
MIMO	Multiple Input Multiple Output
MVNO	Mobile Virtual Network Operator
NDMA	National Disaster Management Authority
NDRF	National Disaster Relief Force
OPEX	Operational Expenditure
P25	Project25
PGMN	Portable GSM Mobile Network
PMR	Private Mobile Radio
PMRT	Public Mobile Radio Trunking Service

PPDR	Public Protection and Disaster Relief
PS-LTE	Public Safety- LTE
PSTN	Public Switched Telephone Network
PTT	Push-to-Talk
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RDM	Relayed Device Mode
SDR	Software Defined Radio
TCCA	TETRA and Critical Communications Association
TDD/FDD	Time/Frequency Division Duplex
TDMA/FDMA	Time/Frequency Division Multiple Access
TEDS	TETRA Enhanced Data Services
TETRA	TErrestrial Trunked RAdio
TRAI	Telecom Regulatory Authority of India
TSDSI	Telecom Standards Development Society India
UHF/VHF	Ultra/Very High Frequency
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network

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