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TECHNOLOGY OPTIONS FOR PUBLIC SAFETY AND DISASTER RELIEF NETWORKS

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Abstract
The rise in global cases of emergencies as a result of man-made and natural disaster necessitates the need for a robust and reliable means of communication networks. The partial or complete, disruption of telecommunications infrastructure as a result of disaster has caused delays in emergency response and disaster relief efforts, leading to loss of lives and damage to properties. Although, modern telecommunications networks have reliability and resiliency to physical damage, however, the risks associated with communications failures remain a major issue as the severity of the damages may depend on the underlying technologies and architecture used. It is however important to also note that each technology option available for public safety network has its own unique characteristics. Some of these options are widely deployed for commercial purposes in Nigeria, while others are still in the developmental stages. This paper therefore outlines some of the existing, new and affordable technological options, available today that can be deployed for public safety and disaster telecommunications networks in Nigeria. Furthermore, the paper recommends that the national broadband network plan needs to be aligned to the current commercial deployments of the 4G Long Term Evolution (LTE) wireless services, this is to ensure that the pace is maintained with the changes in the technology and leveraging cost efficiencies for the public safety networks.

Keywords: Public Safety; Disaster; Telecommunication; Technology options

1. Introduction

Public Safety Networks (PSNs) are essentially wireless communications networks used by emergency services organizations. It is basically providing 24-hour communication facilities in response to natural and man-made disasters, such as medical emergencies, threats to public order and a host of other life-threatening situations (Arthur, 2012). This is conventionally expressed as a governmental responsibility of each country. The primary objective of the public safety is prevention and protection of the public from threats or disasters. Public Safety (PS) organizations such as National Emergency Management Agency (NEMA) in Nigeria, Federal Road Safety Corps (FRSC), Law Enforcement Agencies (i.e., police and the military), fire departments and Emergency Medical Services (EMS) are crucial in disaster preparedness and recovery. The critical role played by the EMS is assisting in the response to emergency events.

The first responders are typically the law enforcement agencies such as the police, and then other responders are the fire-fighters, and emergency medical personnel (ambulance). Therefore, the ability of the first responders to communicate effectively in an emergency situation would determine the safety level. The public safety of Nigerians especially those in the North-Eastern part of the country becomes a very big issue with the frequent attacks from a sect called Boko Haram. It became so alarming when the base stations of mobile service providers were destroyed and people in this part of the country became incommunicado. It equally made it impossible for agencies to communicate with each other and the people in the communities could not relay any forehand information of an intended attack to the necessary security agencies.

In Nigeria, different public safety agencies like NEMA and FRSC do not have a common means of communication, with a few deployments of mobile land system, and so it is the public mobile service that had been attacked that these agencies rely on to communicate with each other, especially during an emergency situation. Globally, there are several cases in which the communication infrastructures are damaged such include: the Indian Ocean tsunami of December 2004 (Townsend and Moss, 2005), New York City, September 11 terrorist attack (NCTA, 2004), the 1995 Kobe, Japan, earthquake (Kobe, 2017), the 1989 Loma Prieta earthquake (Barnum, 1994), the Kocaeli-Golcuk Earthquake of August 17, 1999 (George P. C, 2017) and many others. In all these situations, telecommunication infrastructures were physically damaged or disruption of supporting infrastructure such as transportation and electricity grid. High traffic volumes of users causing congestions also contribute in the same way of disrupting the telecommunication service. Whether partial or complete, disruption of telecommunications infrastructure as a result of disaster causes delays and errors in emergency response and disaster relief efforts, leading to loss of lives and damage to properties, which are all preventable with the help of first responders (Townsend and Moss, 2005). Although, modern telecommunication networks have reliability and resiliency to physical damage, however, the risks associated with communication failure remain a major issue due to dependence upon these tools in emergency operations (Mitchell and Townsend, 2004).

In recent years, Nigeria has seen an improvement in the commercial communications infrastructure, and also increased in subscribers and teledensity from 2.2 million and 1.89 to 149 million and 108.1 from 2002 to first quarter of 2016 respectively (NCC, 2016). Although the capabilities of the commercial communication systems have greatly improved, the same cannot be said for the communication systems used by most public safety and disaster relief agencies. Based on information available to the authors indicate that our public safety and disaster relief agencies utilize cellular mobile phones for emergency communication and responding to disaster cases like motor accidents, bomb blast, floods, gas explosions and etc. Due to the shortcomings of the traditional cellular systems, today's public safety communications systems in Nigeria are prone to network congestion, interoperability problems, which make it very difficult for first responders from different agencies and locations to communicate and coordinate. This also, undermines the inter-agency communications.

In Sept 2012, the Nigerian government, through the ministry of communication technologies, released the 2013-2018 National Broadband Plan (NBP) (NBP, 2012), which maps out strategies and recommendations for improving access across the country. The NBP plan had identified the role of broadband in public safety and emergency response. Although, government proposes to establish Emergency Call Centres (ECC) in all the 36 states of the federation and the FCT with a three-digit emergency code number, known as E112 with the promise that when people dial 112 the call goes to the nearest ECC. However, in the NBP, there were no provisions and clear-cut strategy for creating a public safety broadband infrastructure in the country. Most likely, this added service (i.e. ECC) may rely on the underlying commercial mobile cellular infrastructures.

In order to provide reliable public safety network infrastructure, there is the need to consider available options. It is however important to note the geographical location and local terrain of environment which are the major issues to be considered when deploying telecommunication infrastructure to provide access. Each option has its own unique approach to serving the public and has its own advantages and shortcomings. Some of these options are widely deployed for commercial purposes in Nigeria, while others are still in the developmental stages. This paper therefore, outlines some of the existing, new and affordable technological options, available today that can be deployed for public safety and disaster telecommunications networks in Nigeria.

2 Disaster Management Cycle

Disaster can be defined at different levels of household; community; district; state; national and international, as an unforeseen event that occurs suddenly which is highly overwhelming. Depending on the level of occurrence of the disaster, calamities such as economic and social, serious illness and even death could be experienced. Examples of disaster that can be encountered are displacement of people as a result of conflict, earthquake leading to buildings collapse, livelihood destruction, fire outbreak, flood and even epidemic (Abdallah and Burnham, 2008). Most recent of man-made disaster are the use of bombs and other means to attack, kidnap, and kill large number of people.

Disaster management cycle includes: Warning phase, Response phase, Preparedness phase, Reconstruction/Rehabilitation phase and Prevention/Mitigation phase. Figure 1 provides a conceptual diagram of disaster management cycle. A *warning phase* usually precedes a disaster, which is subsequently followed by *a response* which can only be substantiated with the level of *preparedness* in place. During the emergency phase, efforts are made to bring succor to the affected and this transforms into the *reconstruction or rehabilitation phase.* To prevent same type of disaster from reoccurring, experiences of the previous occurrences are used for *mitigation* and to be very ready in case of reoccurrence. Figure 1 presents the four main different stages encountered in case of a disaster. Even though, the phases are in a cycle showing occurrence in sequence, but some may occur at the same time. The consequences of disaster most times go beyond the reconstruction phase, which is not shown in the block diagram.

In a situation where there are insufficient resources to take care of the reconstruction and mitigation, then another disaster might occur (Abdallah and Burnham, 2008).

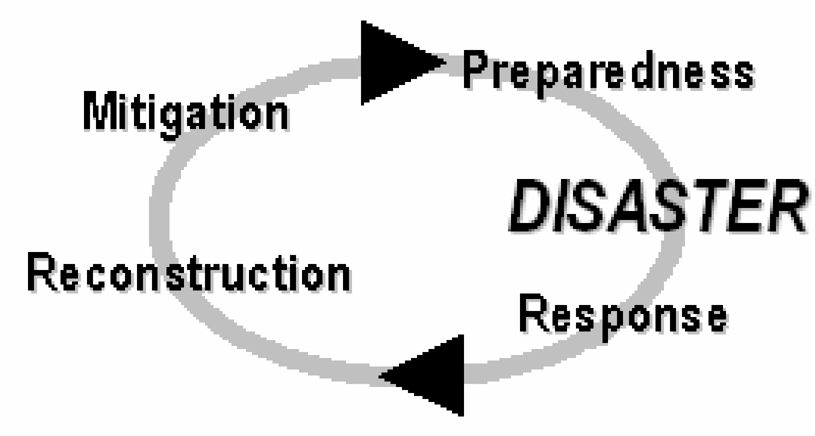


Figure 1: Disaster management cycle

3. Public Safety Networks

3.1 Roles of the Public Safety organizations

Public Safety (PS) organizations are very important in preparing for disaster, ensuring recovery and helping in taking care of emergency events like disasters that are catastrophic. Law enforcement, fire-fighters, emergency medical personnel, and others are those usually found in an emergency scene. Non-governmental and military organizations, volunteer groups and other local and national organizations are those found when the disaster is a large one. The schematics block diagram of the main functions of PS is given in Figure 2 (Baldini *et al*, 2013).

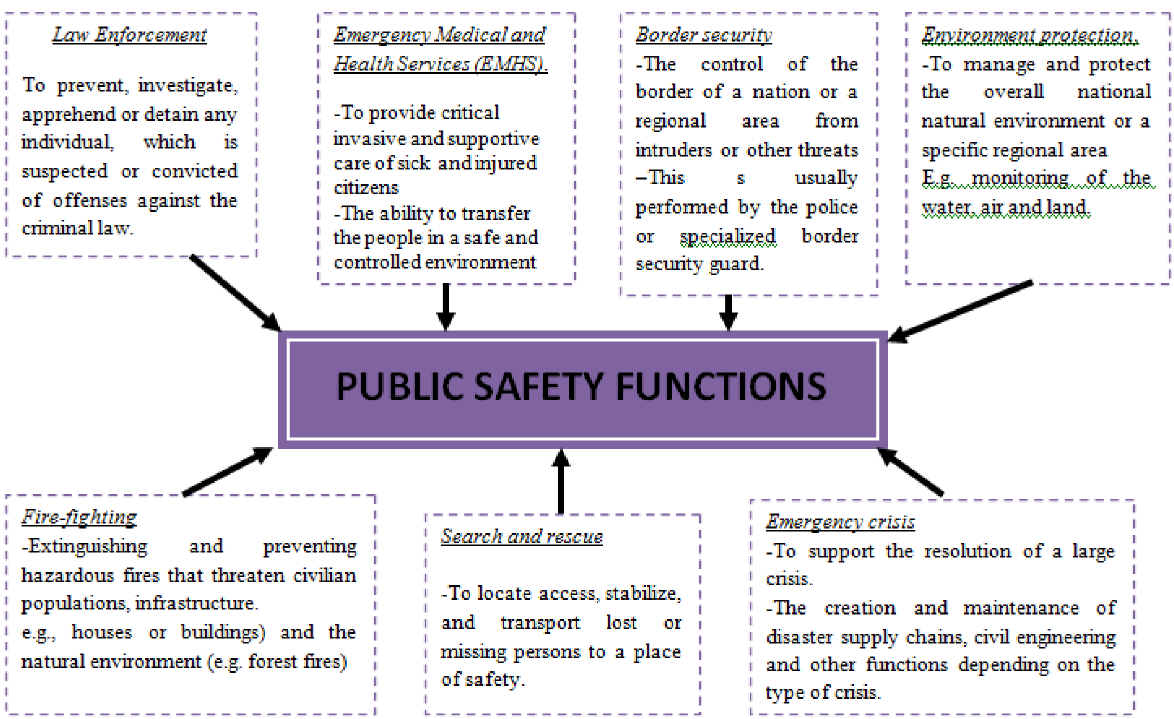


Figure 2: Provides the schematics of the main functions of Public Safety

Police, fire-fighters, border guards, coastal guards, medical associations and non-governmental organizations (NGOs) are functional as described in Figure 2, at local, national and regional levels. The relationships between organizations and functions are highly dependent on the concerned country's legislation (Baldini *et al*, 2013). Fragmented networks and obsolete wireless technologies limit the first responders. The use of nationwide public safety wireless broadband network that are cheap to acquire will make access to advanced, cutting edge technologies and applications available to the public safety agencies to ensure improved emergency response capabilities. In any case, all arms of government and the private sectors must cooperate for transition from traditional land mobile radio (LMR) communications to broadband to be effective and operational (Homeland Security, 2011).

3.2 Areas of applications of PSDN

PS networks have diverse areas of applications (Baldini *et al*, 2013), *which* include: Verification of biometric data, whereby potential criminals have their features like fingerprints checked during patrol by the PS officer. Remote monitoring and video surveillance done wirelessly where a fixed or mobile sensor records and distributes data in video streaming format to enable the PS responders and Command and Control centers share files is also an application. The use of camera to take pictures of plate numbers of vehicles and the images are transmitted to the headquarters where verification is done is a description of another application called automatic number plate recognition. Documents scan used during patrolling or border security operations; database checks, in this case, data are obtained from the headquarters to assist the PS officers in automatic vehicle or officer location operation.The PS officers have a GNSS (e.g., GPS) position localizer on the terminals.

The Decision management team makes use of the positions transmitted from time to time to the headquarters. This application is especially found very useful when there is fire outbreak or earthquake and people are trapped. Remote emergency medical service in which video and data are transmitted is also found to help the medical personnel to work with the team on the field in case there is an emergency patient. Figure 3 provides areas of application of PS Networks and respective data rates requirements (DRQ).

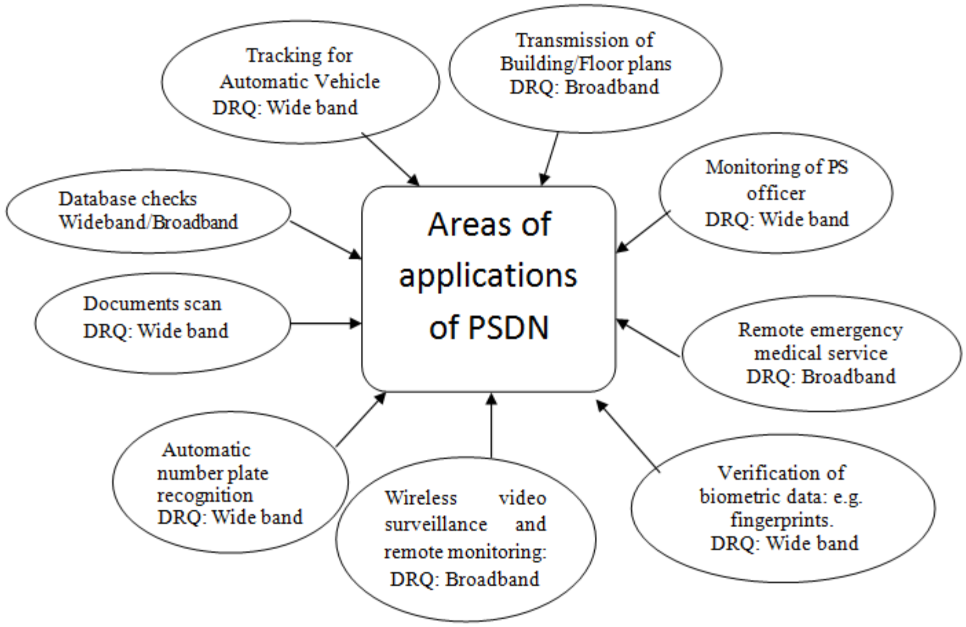


Figure 3: Areas of Application of PS Networks

3.3 Special features of PSDRN

Backup in the transmitters and power supplies with very rugged handheld devices, protection against being brought down by hoodlums are required by highly dependable public safety systems. Sufficient capacity for unusual periods must be available on public safety communication systems, especially when emergencies occur that a lot of first responders are needed. In most cases, the public safety systems have unused capacity because they carry less traffic, especially the mission-critical ones. Spectral efficiency would be increased and possible cost reduction would be experienced if sharing of resources is allowed (Peha, 2007). Voice, Data connectivity, Text Messaging, Push-to-Talk and Security services are the basic services for PS communication systems (Baldini *et al*, 2013).

4. Technology options for PSDRN

4.1 Land Mobile Systems for PSDRN

i. Paging Systems

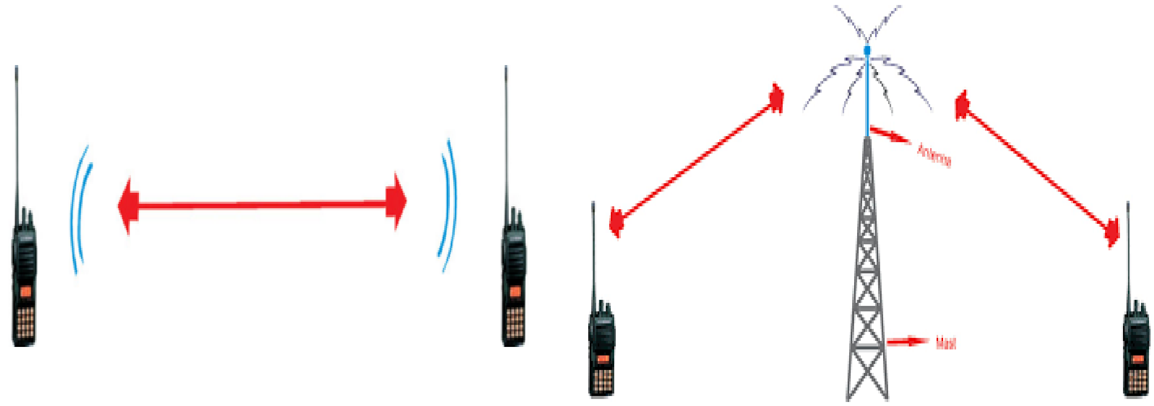
Paging systems are generally single-band (frequency), simplex radio system which is able to display messages received as numeric messages or announces it as voice messages. Simplex pagers which are also commonly known as “One Way Pagers” can only receive messages, although, two-way pagers can receive and acknowledge, moreover, they can also originate messages using an internal transmitter (Pager, 2016). Common wireless paging systems include wireless smoke detectors, push buttons calls, ambulating patient help pager, Infrared room locator, wireless pull cord station etc. Figure 4 shows a typical synchronizing paging system. The major shortcoming of this type of technology is that it operates in a half duplex mode with single frequency this therefore, limits its capacity.

Figure 4: Synchronous paging system (Pager, 2016)

The deployment of Paging Systems was achieved at different frequency bands, i.e. the VHF (Very High Frequency), UHF (Ultra High Frequency), and FM (Medium Frequency). There were many standards set for the operation of the system but the popular ones being the British Post Office standard, called POCSAG (Post Office Code Standardization Advisory Group), and Motorola's FLEX system (Kathy and Hart, 2003).

ii. Two-Way Simplex Radio Systems

Unlike the pagers, two-way radio systems operate on half duplex mode and can both transmit and receive but not at the same time. Two-way radios can be implemented as Ad-hoc network as in the case of walkie-talkies or with base stations. Figure 5 shows a two-way radio system. One advantage of this system is that it can operate both in VHF and UHF bands, except the 220 MHz band. Very long distance communication can be achieved with high power and high transmitter in the case of base station. However, one major problem is that the system has very low antenna heights, and this limits the communication range to usually few miles in flat terrain (Kathy and Hart, 2003). However, this limitation is associated to only handheld and mobile radio systems. Although, repeated transmissions from one mobile to another could alleviate this problem and this gives rise to the development and deployment of mobile relay or repeaters.



(a) (b)

Figure 5: Two-way radio system (a) Repeater operation (walki-talkie) and (b) Using base station (infotrunk, 2016)

Power and coverage limitations of the handheld and mobile two-way system can be enhanced using two-way relay systems. This is commonly referred to as mobile repeaters as shown in Figure 6. In this case, the repeater uses the two frequencies, one in uplink (input) and the other downlink (output). The primary function of the repeater is to function as an amplified relay station, whereby, low-power base stations signals from low-level mobile, and handheld could be received, amplified and re-transmitted on another frequency. The output frequency is different from the inputs. Usually, these types of repeaters are installed on the highest points within the coverage areas such as in high buildings and mountain tops where the elevation allows signal to travel far and thus, achieving maximum coverage and penetration. The coverage distance could be above 60 miles in radius. The repeater stations transmit with very high-power 600 to 3,500 watts ERP (Kathy and Hart, 2003), depending on the need and this can cover a large area.

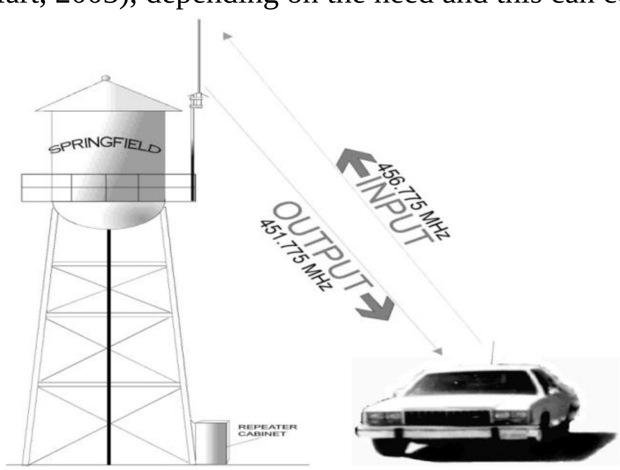


Figure 6: Two-way repeater stations (Wiki, 2016a)

Another problem that could arise with using this type of system is shadowing due to the movement of the mobile radios, within mountainous terrain or in urban areas where tall buildings and other shadowing objects could block the transmission. In these areas, the radio signal from the handheld system may not be detected by the repeater site considering the fact that the handheld radios, transmit with very low output power, typically, of range between 0.5 to 3 watts ERP (Kathy and Hart, 2003). However, satellite receiving sites could be deployed in the areas where there could be potential low-power radios. The satellite would receive the low signal and transmit via telephone line or microwave radio transmission to a signal comparator at a central site. The satellite in this case, would serve as backhaul. This scheme is illustrated in Figure 7.

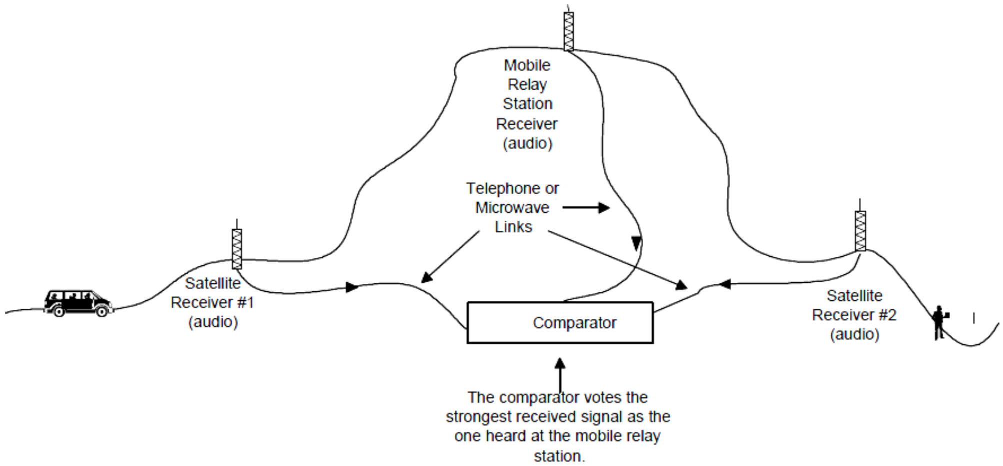


Figure 7: Satellite and Mobile relay system (Kathy and Hart, 2003).

In some situations, small vehicular repeaters or mobile repeater could be used.

iii. Trunked Radio Systems

One of the biggest challenges with the repeater system is scalability. For example, in developed countries like the USA, many of their communities use separate repeaters for the first responders (i.e. police department, the fire department and the likes). Moreover, other non life threatening services such as the administrative and road maintenance departments also make use of these repeaters. Due to the system of allocation, each unit is assigned a dedicated channel, in a situation when a department such as police is using two repeaters for its operation and another department's repeater is available, the police department may not be able to use it as it may cause interference. This raises the issue of scalability. The trunk radio system was proposed by research community to mitigate these problems. The trunk system consists of computer-controlled two-way radio system that allows sharing of few radio frequency channels among a large group of users (Solid Signals, 2015). This allows flexibility in the spectrum usage as it allows a pool of channels be shared to many different groups of users which is in contrast to the conventional two-way radio system where a dedicated channel (frequency) for each individual group of users. Figure 8 provides simple illustration of trunk radio system.

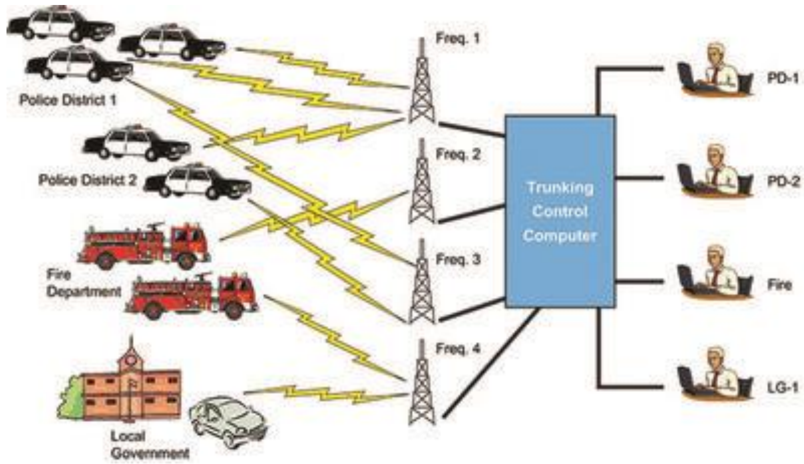


Figure 8: Trunk Radio Systems (Solid Signals, 2015)

Two main types of TETRA network architectures were defined by (Mikuli and Modlic, 2008), the conventional systems that use centralized Switching and Management Infrastructure as illustrated in Figure 8 and recent systems with distributed network architecture.

The centralized TETRA system is the most widely deployed as more than hundred of base stations can be deployed with single central network switching. This makes the call set-up times to be short and possibility of Quality of Service control. However, the distributed architecture is commonly referred to as TETRA over IP networks, have also been implemented but with few number of base stations at about 50 base stations (Mikuli and Modlic, 2008). This raises scalability issue. However, it is possible to scale-up the number of BTS but there is a risk of performance degradation. In order to achieve tradeoff, a hybrid system could be implemented based on a centralized IP based system. TETRA could also be integrated with Wireless LAN (WLAN) technologies (Salkintzis, 2006) to provide more enhanced service delivery, such as broadband data connectivity, voice transmission delays, improved voice quality and simultaneous reception of many group calls since WLAN is based on IP multicast and VoIP technologies. Table 1 provides comparison of TETRA with other different public safety technologies.

Table 1: Comparison of different public safety technologies

Technologies	Frequency Band	Spectrum	Carrier Bandwidth and Downlink	Coverage	Mobility Support	Security and QoS Support	Comments
Project 25	50 MHz 150 MHz 170 MHz 220 MHz 410 MHz 500 MHz 750 MHz 800 MHz	Licensed	25/12.5 kHz and 9.6 kb/s	Wide area	Yes	Yes	Low data rates, the puh-to-chirp latencies is quite low
TETRA voice + data	390 MHz 420 MHz 450 MHz 900 MHz	Licensed	25 kHz and Up to 28 kb/s	Wide area	Yes	Yes	Low data rates, the puh-to-chirp latencies is quite low
TETRA enhanced data service	390 MHz 420 MHz 450 MHz 900 MHz	Licensed	50/100/150 kHz 473 kb/s	Wide area	Yes	Yes	Applications that use large bandwidth and multimedia messaging are well supported. Also image transfer has high resolution
TETRA advanced packet service	390 MHz 420 MHz 450 MHz 900 MHz	Licensed	200 kHz and 473 kb/s	Wide area	Yes	Yes	Applications that use large bandwidth and multimedia messaging are well supported. Also image transfer has high resolution
TIA-902	Upper 750 MHz	Licensed	50/100/150 kHz 690 kb/s	Wide area	Yes	Yes	Applications that use large bandwidth and multimedia messaging are well supported. Also image transfer has high resolution
Cellular	400 MHz 450 MHz 700 MHz 800/900 MHz 850 MHz 900 MHz 1800 MHz 1900 MHz 2100 MHz	License/ Unlicensed	Flexible bandwidth for some technologies Details in Table 2.	Wide area	Yes	Yes	Global compatibility and a large number of users can be taken care of. Coverage is limited. Total network failure when hit by major disaster.
WLAN (IEEE802.11a)	5 GHz	Unlicensed	6 – 54 Mb/s	Wide area	Yes	Yes	Cheap alternative for access to the Internet for disaster network. It offers less RF interference. Coverage, interference and line of sight requirements in hilly or heavily foliated terrain could be major challenging factors.

4.2 Wireless Cellular System

Cellular technology was originally designed for mobile services, such as communication from moving vehicles. In developing countries like Nigeria, wireless cellular communication systems provide primary access to telephone services through portable handsets. This has to be because of the inefficiency and near-collapse of wireline technology. Figure 9 shows a typical architecture of mobile cellular system, it consists of base transceiver stations each covering a geographical area call cell. Each cell or base station is connected to the mobile telephone switching center via backhaul network. The backhaul technology could be wired such as fiber and ADSL or wireless such as microwave, satellite or the emerging Television White Spaces (TVWS). Cells range can vary from 10 meters (femto cells) up to 35 kilometers (macro cells) and above. The macro cells are deployed outdoor and are able to provide 2G, 3G and 4G services in range of kilometers and are backhauled via fiber optics and/or microwave (Faruk *et al.,* 2016). This is typically suitable for public safety communications as it covers wide area with minimal number of sites. The major challenge is the power consumption. Mostly, developing countries do have shortage in power generation and transmission and such macro base stations consumes between 1.7.kW-5 kW depending on the type of the sites (Faruk *et al.,* 2012). Most of the commercial operators rely on diesel generators to power-up the sites. This type of solution may be unsustainable for public safety deployments. The good news, Nigeria is a temperate region with abundance of solar energy, therefore, sustainable solar energy solution is very feasible and this has been proposed by (Faruk *et al.,* 2012a) or a hybrid or solar and any other renewable solution such as wind power. These systems are found to be very reliable compared to diesel alone ((Faruk *et al.,* 2012c).

Two common cellular technologies that have become the toast of Nigeria are the Global System for Mobile Communications (GSM) and Code Division Multiple Access (CDMA). In the US and Canada, GSM operation is on 850 MHz and/or 1900 MHz. In Nigeria, GSM uses the time division multiple access (TDMA) technique to multiplex up to 8 calls per channel in the 900 MHz and/or 1800 MHz spectrum bands. CDMA is a 3G network which uses Direct Sequence Spread Spectrum, DS-SS, and communication system to support voice and data communication. The two popular CDMA standards are the WCDMA and several variants of CDMA2000 (Adediran *et al.,* 2016). The frequency bands used by 3G networks include the following: 2500-2690 MHz, 1710-1885 MHz and 806-960 MHz. More advanced technologies such as the 4G LTE are at early stage of deployment. However, Table 2 provides comparison of different cellular technologies. Some of the advantages of cellular system are:

- Global compatibility and very large number of subscribers can be accommodated.
- Due to large chunk of available bandwidth, cell capacity can easily be increased to accommodate more users or traffic demand.
- Adaptive power control and interference management systems
- Reliability is very high even under the worst environmental conditions.

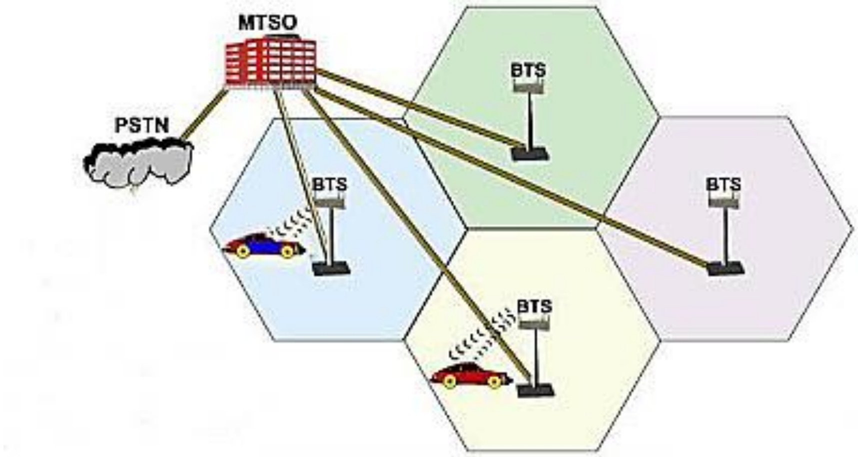


Figure 9: Cellular Telephone System: Chapal (2010)

Cellular mobile phones i.e. the GSM systems have been used for over a decade for public safety communication in Nigeria and this has been the sole, dominant technology option. However, due to the favourable propagation characteristics of CDMA 450, wider coverage could be provided and it has lower overall capital and operational expenditure when compared with other access technologies such as the HSPDA, WCDMA and GSM. Also, it is expected that CDMA 450 will provide less penetration loss through buildings when compared with others (Adediran et al., (2015). More enhanced technologies such as the LTE systems are evolving; these technologies provide more flexibility and data capacity than the already deployed 3G and 3.5G systems. In addition, LTE systems have an inbuilt public safety features, the performance of LTE in terms of capacity, reliability and security is enough to fulfill the strict requirements of the public safety users (Simić, 2012).

Table 2: Comparison of different Cellular technologies.

Technologies	CDMA2000	GSM/GPRS /EGPRS	UMTS/HSDPA	LTE	802.16x	5G Technologies
Frequency bands	450 MHz	850 MHz 900 MHz 1800 MHz 1900 MHz	1900 MHz 2100 MHz	400 MHz 700 MHz 800/900 MHz	10 – 66 GHz LOS	28 GHz
Expected frequency reuse	1/1	4/12 on first carrier; 1/3, 1/1 on others	1/1	1/1	1/1, 1/3	
Spectrum	Licensed	Licensed	Licensed	Licensed	Licensed and unlicensed	Licensed and unlicensed
Carrier Bandwidth	1.25 MHz	200 kHz	5 MHz	1.4 MHz up to 20 MHz	Scalable (1.25 –20 MHz)	800 MHz
Coverage QoS	Wide area Yes (with 1xRTT and EVDO Rev	Wide area Yes	Wide area Yes	Wide area QoS class identity (QCI)	Wide area Yes	Wide area Yes
Data Rate	3.1 Mbps downlink, 1.8 Mbps uplink	114 kb/s/473 kb/s	14.4 Mb/s downlink, 384 kb/s uplink	300 Mb/s downlink, 75 Mb/s uplink	30 Mb/s (in 10 MHz FDD)	35.46 Gb/s
Mobility Support	Yes	Yes	Yes	Yes	Development of 802.16e is considered in its planning.	Yes
Multiplexing	Frequency division multiplex	Frequency division multiplex	Frequency or time division multiplex	Frequency and time division multiplex	Frequency or time division multiplex	Multiplexing millimeter-wave
Comments	IP based Multimedia Subsystem (IMS) signalling framework make information readily available and also make access to state of the art applications easy for the PS officers.	lack of peer-to-peer communication	IP based Multimedia Subsystem (IMS) signalling framework make information readily available and also make access to state of the art applications easy for the PS officers.	Main advantage is in the simplicity of its IP system architecture. The main disadvantage is the lack of peer-to-peer communication and very high cost	lack of peer-to-peer communication	Expected Advantages - Higher number of simultaneously connected devices, higher syste spectral efficiency, lower battery consumption, lower outage probability (better coverage), ower latencies, lower infrastructure deployment costs, higher versatility and scalability, or higher reliability of communication

Some of the major problems of using terrestrial cellular network are the limit of the cellular coverage and failure of the network in the event of major disaster. In the event of disaster happening outside the coverage radius of the cells, it will be practically impossible for the mobile to communicate with the network. Therefore, it is expected that during major emergency operations, such as natural or man-made disasters, both the commercial and dedicated terrestrial networks will fail to provide the necessary support due to destruction of the network infrastructure. In other to mitigate this problem, Casoni *et al.*, (2015) proposed a cellular System with integrated Satellite Backhaul for both infrastructure-based and infrastructure-less scenarios. The paper provided field operators and people in distress with easy access and guarantee quality of service when the underlying terrestrial infrastructures are lacking or failed. This features helps to expand coverage, capacity and network resilience when compared to the conventional systems. Figure 10 shows LTE System with integrated Satellite Backhaul.

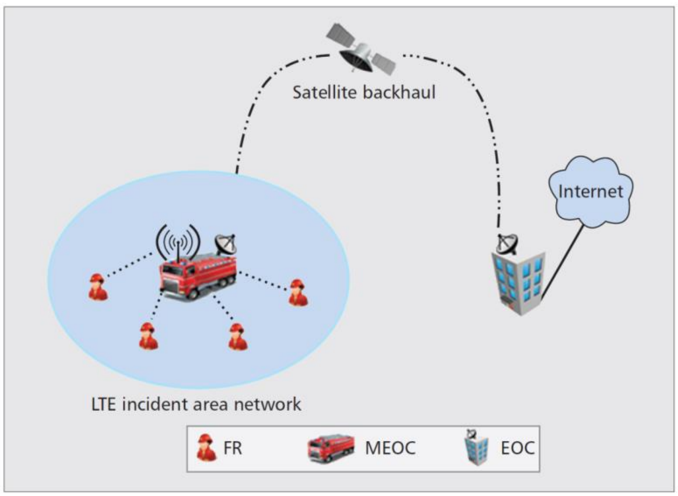


Figure 10: LTE System with integrated Satellite Backhaul (Casoni *et al.*, 2015)

In Figure 10, LTE was considered to be the access technology, while, the satellite is used as the backhaul linking the LTE base stations and the internet. In the architecture, a Mobile Emergency Operations-Control Center (MEOC) acts as the access technology and this provides First Responders (FRs) with a LTE Incident Area Network (IAN), thus representing a deployable (and mobile) LTE repeater station for field operators (Casoni et al., 2015). The satellite link serves as the backhaul medium between the MEOC and the Emergency Operations-control Center (EOC), which is non-mobile and represents the operations headquarters of the public safety authorities (Casoni et al., 2015). In this architecture, FRs, MEOC and EOC will be able to communicate irrespective of the geographical locations.

4.3 Wireless LAN (WLAN) and (WMAN) Technologies

Wireless LAN (WLAN) technology was designed to provide high speed wireless connection in a local area. WLAN supports two architectures, namely: the infrastructure-based, also known as centralized system, which is based on a central controller called access point, and decentralized or ad-hoc architecture which does not require any infrastructure to be in place. WLAN have been deployed widely in individual homes and businesses. Most of the government agencies, Universities in Nigeria and Internet cafes today utilize the WiFi technology for Internet services. This service could be extended to voice by employing the use of software, such as Skype, to communicate. Figure 11 shows a typical wireless local area network.

Figure 11: Wireless Local Area Network (WLAN, 2014)

Wi-Fi is one of the WLAN technologies belonging to the general family of IEEE 802.11 standards. Some of the strengths of WLAN are: It is a relatively cheap alternative for access to the Internet for disaster network and no spectrum licensing is required as it operates in the unlicensed ISM band. However, coverage, interference and string line of sight requirements particularly in hilly or heavily foliated terrain could be major challenging factors.

Wireless metropolitan area network (WMAN) technology is based on broadband wireless access (Kuran and Tugcu, 2007). There are two major standards for WMAN technology, namely, IEEE 802.16 (WiMAX) and IEEE 802.20 (Mobile-Fi). However, IEEE 802.16 WiMAX is the global most acceptable standard which aims to provide broadband Internet service in urban, suburban and rural areas. The IEEE 802.16 standard (Ghosh *et al,* 2005) supports two architectures, namely, last mile access and mesh network architectures. In last mile access architecture, the base station (BS) controls the transmission to/from the subscriber stations (SSs), which is similar to the cellular architecture. In mesh network architecture (i.e. IEEE 802.16j), the SSs can relay traffic from other SSs to the BS in a multi-hop fashion. As earlier started, the WLAN could be integrated with the TETRA system to provide more enhanced service delivery during disaster operation. Figure 12 gives a typical deployment scenarios of WMAN.

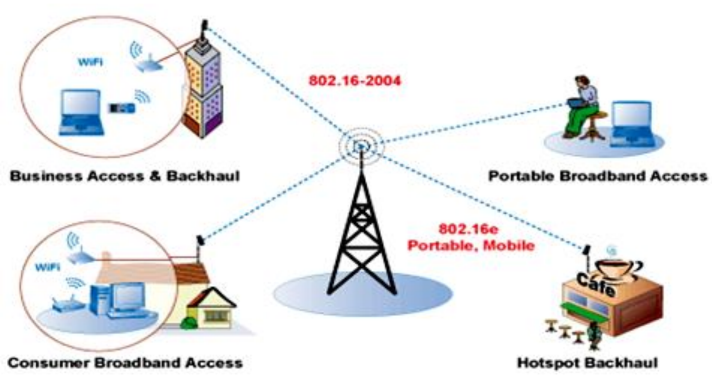


Figure 12: An example of WIMAX providing Internet Access source: (Frank *et al*, 2013)

IEEE 802.16 with single carrier air interface operates in the 10 - 66 GHz band with LOS communication. IEEE 802.16a with OFDM/TDMA air interface operates in the 2 - 11 GHz band with non LOS communication. There is also IEEE 802.16e which supports broadband wireless access for high mobility. Contrary to WLAN, WMAN technologies could theoretically extend the range up to 50 km with a single tower. In terms of cost, data rates, flexibility and user mobility, WMAN could be a very good candidate for PSDN. Although, the Initial cost of deployment, site installation and maintenance could be issues to worry about since the network will be deployed for public service. The network still operate on unlicensed spectrum, therefore, problems of interference could manifest if the network is deployed in urban centers where the usage of WLAN technologies is high.

4.4 Emerging Technologies for PSDN

LTE Device-to-Device (D2D) communication and eCall are two dominant emerging technologies for future public safety and disaster relief network.

(i) LTE Device-to-Device (D2D) communication

D2D communication enables direct communication between nearby mobiles as illustrated in Figure 13. It does this by enabling mobile devices to discover the presence of other devices in their vicinity and to communicate with them directly, with minimal involvement from the network (Brydon, 2014). Fodor *et al*., (2014) proposed D2D communications as an underlay to Long Term Evolution (LTE) networks as a means of harvesting the proximity, reuse, and hop gains.

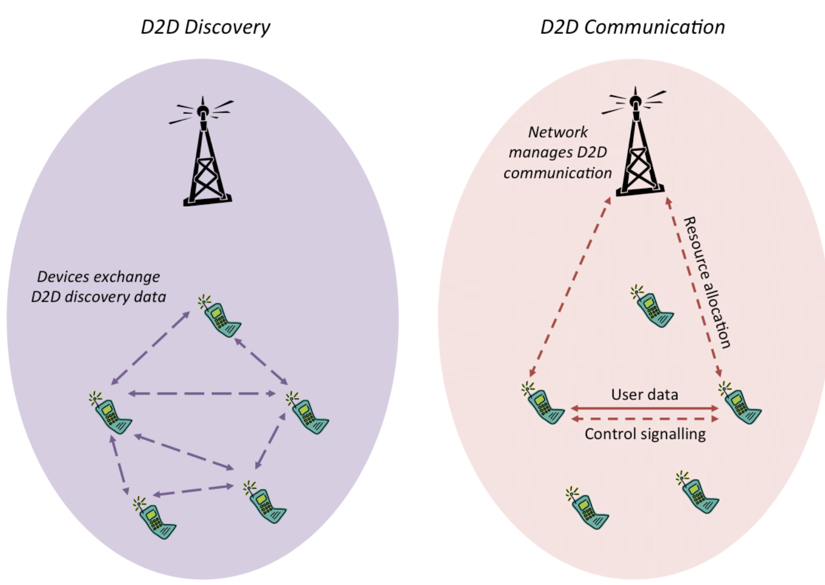


Figure 13: D2D communication (BRYDON, 2014)

D2D is expected to facilitate the interoperability between public safety communication networks and other commercial networks. The 3GPP solution for D2D is termed Proximity Services (ProSe) and has two main components (Brydon, 2014), as shown in Figure 12.

- *D2D Discovery*: this enables a mobile device to use the LTE radio interface to discover the presence of other mobile capable devices in its vicinity.
- *D2D Communication*: the D2D mobile devices use the LTE radio interface to communicate directly with each other, without routing the traffic through the LTE network.

Some of the benefits that could be derived in D2D communications is that the spectrum utilization and efficiency will be greatly improved, network throughput with energy saving could be achieved. D2D standardization is currently under research and one of the major challenge of this type of system is defining the under laying architecture for the network. For example, in Figure 13, it can be seen that difficulties may arise for the devices to communicate in an event of failure in the cellular network therefore, the risks to the long-standing cellular architecture, which is centered around the base station (BS). Similarly, it is still not clear on how to share spectrum resources between cellular and D2D communications. Another shortcoming of D2D is the communication range since the mobile stations are having limited uplink transmit power, the communication range could be an issue. However, it was shown in Babun *et al*, (2015) that coverage could be improved in D2D multi-hop communications with underlying cellular networks.

(ii) eCall for Public Safety

eCall (Öörni, 2014) is a European in-vehicle emergency call system, the aim is to deploy a wireless device or sensors in all vehicles that will automatically dial emergency number in the event of a serious road accident such as head-on-collision. These devices are expected to be mandatory in new vehicle models type-approved in the EU after October 2015 (Öörni, 2014). In the future, deployment of a public safety answering point (PSAP) infrastructure capable of receiving and processing eCalls will become mandatory for EU member states (Öörni, 2015). An overview of the standards of eCall is given in Figure. 14.

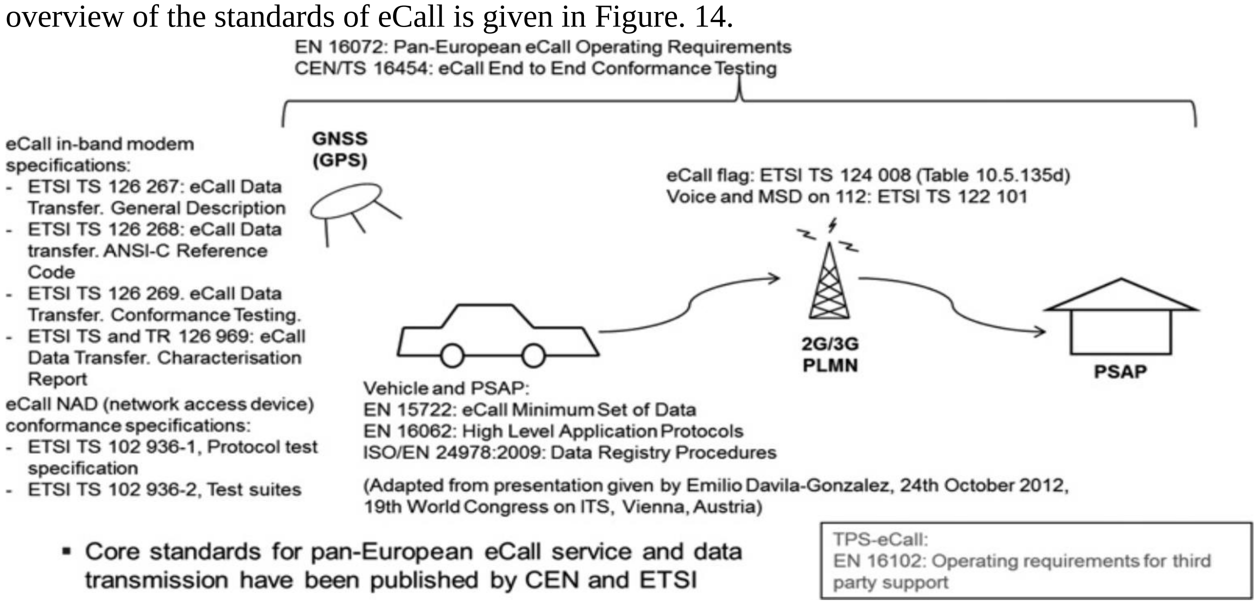


Figure 14: Overview of standards of pan-European eCall (Öörni, 2015)

4.5 Deployment Case Studies

Currently, there is no global dedicated PSDRN infrastructure. However, countries from various regions deployed and implemented different technologies for public safety communications. In Africa, mostly amateur radios (i.e. Land mobile systems) are often used for emergency communication when landline phones, mobile phones and other conventional communications fail or are congested. However other regions like the Europe and the United States of America have a PSDR infrastructure. Table 3 provide summary of the regional PSDRN deployment case studies.

5.0 Conclusions

The need to have a robust and reliable means of communication in the event of an emergency, such as fire outbreak, natural and artificial disasters, medical emergencies, threats to public order such as Boko Haram has been established. All the existing and emerging technological options with their pros and cons are given. This work enumerated all the available options to ensure that viable PSDRN are implemented for safety of lives and properties of the populace. Land mobile systems have been found to be the dominant technology deployed globally for public safety communication. Aside limited capacity, detecting the signal from mobile radios when on motion particularly in hilly or mountainous terrain or in urban areas having numerous tall buildings would be difficult by the repeater site due to low transmit power of the mobile. TETRA systems allow greater flexibility in radio usage and provide more capacity. Cellular mobile phones i.e. the GSM systems have been used for over a decade for public safety communication in Nigeria and this has been the sole, dominant technology option. It is noted that this technology may not be a good candidate for this type of service, moreover, in the event of disaster, the network infrastructure could be physically damaged and high volume of traffic will certainly cause network congestion. In addition, support delivery service such as transportation and fuel may almost be impossible to attain. However, the LTE system has inbuilt public safety features, the performance of LTE in terms of capacity, reliability and security is enough to fulfill the strict requirements of the public safety users. Furthermore, the LTE can be integrated with satellite backhaul for both infrastructure-based and infrastructure-less scenarios. The nationwide public safety wireless broadband network needs to be closely aligned to commercial deployments of Long Term Evolution (LTE) wireless services to keep pace with changes in technology and leverage cost efficiencies.

Table 3: Case Studies

Publications	Countries/ Regions	Technologies deployed	Comments
(WIA, 2015)	Australia	Amateur Radio Landline and mobile phones	Amateur radio deployed for emergencies when landlines and mobile phones fail or are congested
(Tredger, 2015)	Africa	Unified Communications Amateur Radio Trunking with LTE broadband, there is also video surveillance, and video conferencing among others make use of Computer Aided Dispatch system are available	Officials and emergency services providers will find this technology very useful to take care of data that are in very large quantities and incidents can be given quick response that is required. The officials are also equipped with ways to help the victims even after the incidence to help them settle back to normal life.
(Camilla *et. al.*, 2015)	Europe	Terrestrial Trunked Radio TETRA (Trans European Trunked Radio) and later Terrestrial Trunked Radio/LTE	• Group calls (Wide area fast call set-up). • Direct Mode Operation (DMO) allowing communications between radio terminals independent of the network. • High level voice encryption to meet the security needs of public safety organisations. • Priority call (An emergency call facility that gets through even if the system is busy). • Full duplex voice for PABX and PSTN telephony interconnection.
(Baldini,*et. al.* 2015)	France	TETRAPOL	A fixed network infrastructure is considered here.
(Ryan and Jon, 2013)	USA	LTE/The Mobile Emergency Alert System (M-EAS)/Raytheon/ Motorola's Premiere One	PS agencies are given the rare opportunity to utilize the public safety networks such that users could roam into commercial networks with ease. M-EAS is provided for many users at the same time as it relies on digital broadcasting and not on wireless networks. The mobile digital broadcasting is for the provision of media alerts. One Force mobile application was launched in 2012, for first responders to use when they are outside the coverage of Land Mobile Radio (LMR) and they are found to be reliable and secure and at the same time provide real time communication. Computer aided dispatch, records management system are used by first responders to access and share information, as well as from local, state and federal databases.
(Premkumar and Raj, 2014)	China	A Self-Powered Wireless Communication Platform (SPWC)/Self Powered Micro Wireless Ballooned Network	In SPWC, Unmanned Aerial Vehicles (UAV) are deployed in LAP as opposed to High Platform since the High Altitude Platform need the satellite to host the networks which significantly increases the cost. It provides high rate at very low latency and these connections can be used by almost any application that uses IP communication. LTE is basically divided into two parts: the Evolved UMTS Terrestrial Radio Access Network (E-UTRAN). It has multiple wireless balloon access nodes, fixed access point and end devices (mobile PC and IP telephones). During disasters, the wireless balloon nodes connect with each other in the sky to form large ad-hoc networks which are used for emergency communications. The nodes are powered by a solar panel power supply unit or by a power battery for emergency or vehicle on the ground via a very thin wire

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