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Wireless Technologies for Emergency Response: A Comprehensive Review and Some Guidelines

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ABSTRACT Disaster situations require a prompt emergency response. The failure of the legacy (wired) emergency response systems to efficiently cope in such time-critical environments has led to a great interest in wireless-based emergency response systems. In this regard, a number of wireless technologies and systems—each with its peculiar characteristics and pros and cons—have been proposed for use in various emergency response situations. This paper presents, to the best of our knowledge, the first comprehensive survey of the research on this practically important topic. We motivate the use of wireless technology for emergency response and present a comparative analysis of the available wireless technologies. After outlining the scope and requirements of emergency response systems, we provide an overview of the architectures and features of wireless-based emergency response systems and then compare different wireless technologies for different emergency settings. We provide not only details about individual emergency response systems and technologies but also expend efforts to show the forest for the trees to emergency response practitioners—in particular, we provide general high-level guidelines that can help in deciding the right technology for a particular situation, and discuss potential pitfalls from the large-scale emergency-network deployment experience of one of the authors. The emergency response operation is split into five functionalities: we present general guidelines that would help public safety agencies in choosing suitable wireless technologies for each one of them. Finally, we also highlight opportunities and identify the potential areas for further investigation.

INDEX TERMS Body sensor networks, emergency services, wireless communication.

I. INTRODUCTION

The world has experienced an increased number of catastrophic events in the recent years. Major disasters either natural (e.g., the tsunami in South East Asia in 2004, the earthquake in Pakistan in 2005) or man-made (e.g., terrorism activity such as 9/11) inflicted enormous loss of life and uprooted, the communication infrastructure, thus hampering on-site relief activities severely [1]–[3]. The performance of the legacy emergency response systems, being over-reliant on the terrestrial infrastructure, degraded heavily and their limitations became obvious as also presented by the 9/11 commission in its findings [4]. The successive failures of these legacy emergency systems in large-scale disasters has urged public safety agencies to seek for better, reliable and efficient alternatives for recovery and management purposes during a disaster.

The wireless technologies, on the other hand, having unique features including its ubiquitous nature [5], rapid deployment time and freedom to connect to each other, offer a potential solution for executing emergency related tasks. Hence, in a calamity-ridden area where conventional communication infrastructure can get destroyed or become inoperable; and where a fractional delay can become life threatening, a robust, rapidly deployable, and fault-resilient wireless based emergency response system would help carry out emergency rescue and relief operations without disruption in a smooth and effective way. Though many variants of wireless-based emergency systems have been proposed over the past few years, yet a very few could become established or operational as a system. In addition to this, the evolution and latest details of most of these systems are hardly documented/updated online, which makes it difficult for others in the community to benefit from the experience of the designers of these systems. This paper provides a comprehensive survey of the design choices and the current status of the major wireless-based emergency response systems proposed in the literature.

Before delving into the details of these systems, we will motivate the use of wireless based emergency response systems by first identifying the limitations of the tethered systems. In particular, we highlight how wireless technologies has become an enabling technology that empowers public safety and emergency response agencies as well as digital humanitarians [6]. Lastly, we would touch upon the use of wireless technologies for the purpose of development and social good [7].

A. LIMITATIONS OF TETHERED EMERGENCY RESPONSE SYSTEMS

There are several limitations of the tethered emergency response systems that hinder their usage as a first-choice system.

- *Firstly*, *tethered emergency systems* are infrastructure-dependent for their smooth operation [8]. The destruction or overloading of the underlying wired communication network in a disaster leads to communication failure among rescue personnel resulting in an uncoordinated response. On the other hand, wireless emergency systems equip on-site rescue personnel as well as victims with wireless devices to form a self-managing ad-hoc mesh network that acts as the basic communication network among different stakeholders.
- *Secondly*, *bandwidth intensive disaster-site related data* (in the form of high resolution maps and good quality videos)—which may otherwise be used to improve the situational awareness of the high command—is not supported by conventional emergency systems. Modern wireless technologies, accruing benefits of multipathing and cooperative communication, offer high-speed transmissions and have been employed in [**?**], [10], [11] to provide multimedia communication.
- *Thirdly*, *paper-based triage and traditional patient tracking methods* exercised by medics are time-consuming as well as error prone and hence overwhelm the first responders and the hospitals especially in a large-scale disaster [12]. To facilitate medics in triage and to keep the patients' information up-to-date, casualties and medics are equipped with wireless sensors in wireless systems [8], [12]–[20]. The critical parameters including sensors' geographic location are collected for rendering a complete picture to the higher echelon and other emergency departments. End-to-end tracking and health monitoring of victims also enable treatment units to allocate healthcare resources efficiently.

B. WIRELESS TECHNOLOGIES COMPLEMENT DIGITAL HUMANITARIANS

Wireless technologies are also utilized to boost the response of digital humanitarians, a group of volunteers who collaborate over the Internet to gather, process and share big (crisis) data for assisting search-and-rescue (SAR)teams without contributing to the 'data noise' during a disaster [6]. Though use of digital technologies such as Internet, Unmanned Aerial Vehicles (UAVs), crowd computing, social media, etc. has bridged the gap between those 'who need help' and those 'who are voluntarily willing to help' during a disaster [6], [21], embedding wireless technologies in humanitarian activities helps in enhancing the response of digital humanitarians manifolds. For example, survivors of a calamity, using appropriate wireless technologies according to the guidelines outlined in Section V, may volunteer themselves for digital humanitarianism to help provide exact location as well as first-hand information from the disaster site. This would not only reduce the time required to map location on the crisis map but would also allow digital humanitarians to counter disinformation. Furthermore, on-site digital volunteers can facilitate rescue and relief teams in assessing the extent of damage at a site by uploading real-time accurate information in the form of videos and pictures. The SAR teams can utilize this information to organize and prioritize their response action. Additionally, billions of mobile phone subscribers present all over the world may render their services, using the Internet Protocol (IP) connectivity, as translators for disseminating vital content in the languages of the local community in a calamity affected area. Thus, wireless technologies are of great help to expedite digital humanitarians' activities.

C. WIRELESS TECHNOLOGIES FOR DEVELOPMENT AND SOCIAL GOOD

Today, extensive research is being carried out to utilize Wireless Technologies for Development (W4D) [27]. The W4D is aimed at minimizing the digital divide between rural and urban population by enabling Global Access to the Internet for All (GAIA). This calls for devising new network strategies for use in infrastructure-less rural environments, a philosophy that can be extended to address emergency situations as well as to provide prompt response and instant relief. Recent advancements in this direction include the management of Community-Lab wireless networking testbed that can support a large number of hosts. Moreover, TV White Space (TVWS) is also being considered as a viable backhaul option for reaching a large population [28]. Additionally, 3G solutions based on small cells for heterogeneous backhauling have also been suggested for longer sustainability. Smart cell/mobile congestion awareness schemes can improve connectivity by congestion detecting mechanism and thus select the appropriate network automatically [27].

D. CHALLENGES IN INCORPORATION OF WIRELESS TECHNOLOGIES

Various challenges come to the fore during the practical implementation of wireless technologies in disaster scenarios. Most notable of these include interoperability among heterogeneous wireless systems employing diverse standards

TABLE 1. Comparison with existing surveys.

Survey	Publication Venue	Year	Aspects Covered	Wireless Technologies Comparison	Scope & Requirements	No of Systems Surveyed	Selection Guidelines	Implementation Guidelines	Challenges & Open Issues
Kyriacou et al. [13]	IEEE Engineering in Medicine and Biology Society	2009	eEmergency & mHealth	Very few technologies	Not Presented	Overview of 42 Systems	Not Presented	Not Presented	Not Presented
Alemdar et al. [22]	Journal of Computer Networks	2010	eHealthcare	Presented	Not Presented	31 Healthcare Monitoring Applications	Not Presented	Not Presented	Presented
S. Ghafoor et al. [23]	IEEE Wireless Communications	2014	Cognitive Radio for DRNs	Very few technologies	Presented	3 Systems Surveyed	Not Presented	Not Presented	Presented
Baldini et al. [24]	IEEE COMST	2014	Public Safety Applications	Presented	Presented	18 Public Safety Applications	Not Presented	Not Presented	Not Presented
Reina et al. [25]	International Journal of Distributed Sensor Networks	2015	Multihop AdHoc Networks	Very few technologies	Presented	7 Systems Surveyed	Presented	Presented	Presented
Mangla et al. [26]	International Journal of Computing and Corporate Research	2016	Wireless Sensor Networks in Disaster Management	Not Presented	Presented	9 Systems Surveyed	Not Presented	Not Presented	Not Presented
Our Survey	–	2018	Disaster Recovery, eEmergency & Healthcare	Presented Comprehensively	Presented	20 Systems Detailed Survey	Presented	Presented	Presented

and specifications. Network congestion is another challenge that may lead to burdening of limited network resources. A reliable and fault tolerant setup would help in accomplishing the relief task in a befitting manner. Privacy and security of data being exchanged among devices have to be emphasized along with an eye on scarce bandwidth, size or power. In addition to these, achieving robust routing through the use of appropriate routing protocols may also prove challenging. All these factors have to be taken care of along with support for the Quality of Service (QoS). These challenges are elaborated in detail in Section IV.

E. SCOPE AND CONTRIBUTIONS OF THIS PAPER

In this paper, we present a detailed survey of wireless based emergency response systems. We categorize all such systems into three categories—(1) Multimedia-Enabled Networks and Systems, (2) Disaster Recovery & Management Networks and Systems, and (3) Real-time & End-to-End Patient Monitoring Networks and Systems—according to the jurisdiction they have. To provide a solid context for this survey, we present the scope and requirements of emergency systems designed for different circumstances such as natural disasters, terrorism events, battlefield scenarios, and patient monitoring. Emphasizing upon the emerging role of Internet of Things (IoT) in emergency response, we have also included an IoT-based emergency response system [29]. We also describe some popular wireless technologies/standards vis-à-vis throughput and other parameters followed by the comparative performance analysis in Table 2. We also outline technical challenges involved in the smooth operation of these systems.

We present the crux of this paper in the form of general guidelines that may help public safety agencies in the selection of appropriate wireless technology according to the situation demands. Accordingly, we split emergency response operation into five distinct phases, and present appropriate wireless technologies for each phase. We also elaborate key design features that require proper consideration while deploying/designing emergency system for developing countries—we will thereafter compare the systems using these features. The future issues and open research areas have also been highlighted. In literature, a comprehensive survey highlighting all the issues addressed in this paper is missing. There do exist, however, some survey studies in the literature [13], [22], [30], [31] that have focused on e-emergency healthcare, but these studies do not cover other aspects of disaster recovery and management. We conduct a survey of the current research on emergency response systems not only from a disaster recovery and management related perspective but also include the perspective of e-emergency healthcare services in a disaster struck area or in a time-crucial environment. We present a comparison of our survey with aforementioned studies regarding various aspects in Table 1. Furthermore, we present general guidelines on selection of appropriate wireless technologies for various distinguished functionalities of an emergency response process. In the end, we highlight the technical issues and challenges, which need to be overcome, along with the open research areas in deploying an efficient and effective emergency response system.

With a rapid rise in the number of untoward incidents all over the world and failure of the conventional emergency response systems in these incidents, modification of emergency response systems is imminent. Since the 'wireless' option offers a promising alternative, this paper is timely since it can help public safety organizations in choosing the right technology and system according to the scenario requirement.

F. ORGANIZATION OF THE PAPER

The paper has been organized into eight Sections. Section I introduces the area of wireless technologies for emergency response systems. Section II discusses popular and emerging wireless technologies and a tabular comparison of these wireless technologies is presented at the end of the Section. Section III discusses the architectures of existing wireless emergency response systems before presenting the scope and requirements of emergency systems for diverse types

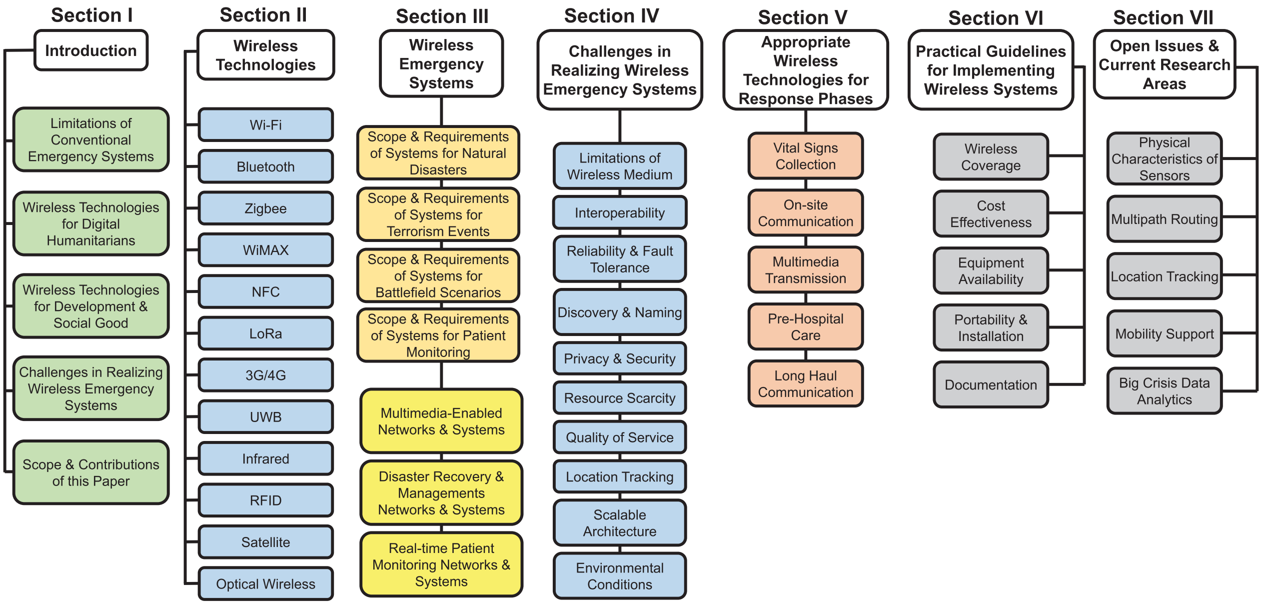

FIGURE 1. A bird's-eye view of the paper.

of circumstances. The main focus is, however, on the wireless technologies employed in Body Area Networks (BAN), Local Area Networks (LAN), Metropolitan Area Networks (MAN) or Wide Area Networks (WAN). The technical challenges/issues related to the operation of these systems have been outlined in Section IV. General guidelines for appropriate wireless technology selection for different functionalities of an emergency response operation are appended in Section V. Practical guidelines for implementing emergency systems in developing countries are elaborated in Section VI. Future issues and open research areas are deliberated in Section VII. We conclude this paper finally in Section VIII. We present Figure 1 to render a bird's-eye view of the Paper to the reader.

II. BACKGROUND: WIRELESS TECHNOLOGIES

In the past few years, wireless technologies have rapidly progressed by adopting innovations in the field of signal processing, communication, and networking. With the improved diversity techniques such as MIMO (Multi Input Multi Output) [32], cooperative communication [33] and mitigated multi-channel interference, these technologies now promise very high data rate [34]. These technologies have revolutionized the world by offering mobility as well as infrastructure-less deployment to the users [35]. This progress has rendered the budget spent over expensive wiring as an overhead, which can be avoided by appropriate selection of these technologies with respect to the given situation.

It is pertinent to mention that although these technologies have been around for quite some time, their comparison regarding efficient utility in various humanitarian and emergency scenarios has not been performed yet. Therefore, in order to make this paper self-contained, relevant technologies vis-à-vis their associated features are presented in this Section. Table 2 contains the comparative performance analysis of these wireless technologies.

A. *Wi-Fi*

Wi-Fi, also known as Wireless LAN (WLAN) and specified by IEEE 802.11 standards, is a network technology and has become essential for data communication in a short range nowadays [35], [36]. There are different variants of IEEE 802.11 in use: the most popular being the IEEE 802.11a/b/g/n variants. These variants operate in the ISM (Industrial, Science and Medical) bands of 2.4 GHz and 5 GHz. With the support of MIMO (Multi Input Multi Output) and efficient diversity techniques in 802.11n, the throughput offered by Wi-Fi has now reached up to 600 Mbps [32]. Since becoming an essential radio access technology of modern wireless devices, Wi-Fi having a range of 10–100 meters and may support a few thousands of nodes [35], [36] is suitable for communication purpose among on-site rescue personnel in a small scale disaster, where infrastructure remains operable.

B. *BLUETOOTH*

Bluetooth is specified by IEEE 802.15.1 and used for short-range wireless communication [35]–[37]. It is designed for small devices having energy constraint and consumes low power, which makes it a smart option for use in emergency environments. The Bluetooth enabled devices can be categorized into three main classifications on the basis of the communication range. The operating range for the three classes are 100 meters, 10 meters and 1 meter, respectively [38]. Bluetooth also operates in the ISM band of 2.4 GHz as Wi-Fi but employs a different spreading

TABLE 2. Comparison of wireless technologies.

Technology (IEEE Spec)	Frequency Band	Throughput	Range	Channel Bandwidth	Success Metrics	Max Number of Nodes
Wi-Fi (802.11a/b/g/n) [32], [36] [35]	2.4, 5 GHz	11, 54–600 Mbps	10–100 meters	20/40 MHz	Flexibility, Speed	2007
Bluetooth (802.15.1) [35]–[38]	2.4 GHz	3 Mbps	10 meters	1 MHz	Cost, Convenience	8
Zigbee (802.15.4) [35]–[37] [39], [40]	868,915 MHz 2.4 GHz	250 kbps	10–100 meters	0.3,0.6,2 MHz	Reliability, Power, Cost	More than 65000
WiMAX (802.16) [8], [35]	2.4 GHz 5.1–66 GHz	35–70 Mbps	0.3–49 kilometers	10,20 MHz	Throughput, Speed, Range	1600
NFC (802.2) [36], [41]	13.56 MHz	106–424 kbps	Less than 0.2 meters	2 MHz	Power, Cost, Convenience	2
LoRa [42]–[44]	0.4–1.0 GHz	Up to 50 kbps	More than 15 kilometers	-	Range, Power, Robustness	Up to 1 million
UWB [35], [37] [48]	3.1–10 GHz	480 Mbps	10–102 meters	More than 500 MHz	Throughput, Power, Cost	236
Infrared (802.11) [35], [49]	300 GHz – 400 THz	4 Mbps	0.2–1 meters	-	Efficiency, Security	2
3G/4G [45]–[47]	400–2100 MHz(3G) 2–8 GHz(4G)	2 Mbps(3G) 200 Mbps(4G)	-	1.25,5–20 MHz(3G) 100 MHz(4G)	Data Rate, Range, Speed	-
RFID [37], [50]	860–960 MHz	10–100 kbps	1–100 meters	-	Cost, Power	2
Satellite (for Teledesic) [51], [52]	24–36 GHz	16 kbps– 64 Mbps (downlink) 16 kbps– 2 Mbps (uplink)	500–1400 kilometers (altitude range) 100 kilometers (radius)	On-demand	Coverage, Cost	In millions
Optical Wireless [53]–[55]	300 GHz– 30 PHz	622 Mbps	More than 10000 kilometers	10–200 MHz	Cost, Robustness Throughput	-

technique of Frequency Hopping-Spread Spectrum (FH-SS) to evade interference [38].

C. ZIGBEE

Zigbee is a standard developed by Zigbee Alliance for ensuring reliable, cost-effective wireless communication along with low power consumption. Zigbee has some additional features to those of IEEE 802.15.4 [37], [39], [40]. In fact, Zigbee utilizes the Physical and MAC layer standards defined by IEEE 802.11 for Personal Area Networks (PANs) and outlines the standards for higher layers of the protocol stack. It operates in ISM bands of 2.4 GHz, 915 MHz and 868 MHz providing data rates of 250 kbps, 40 kbps, and 20 kbps respectively [35], [36], [39]. Zigbee based wireless sensors can be deployed in a calamity-ridden area to collect victim's vital statistic as they can operate even with meager power resources. More importantly, Zigbee devices can interconnect with each other in a self-organizing fashion to form a mesh network that renders services as the basic emergency communication network that operates with little to no infrastructure.

D. WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) is defined by the IEEE 802.16 standard intended for providing high bandwidth wireless voice and data services over a long range in an outdoor environment [8], [35]. Thus, its variants IEEE 802.16a and 802.16d (known as IEEE 802.16-2004) offer a viable last mile and long haul solution for providing Internet access whereas its version 802.16e is suitable for end devices. In the context of emergency response, WiMAX seems apposite for carrying out long-range site-headquarters communication. Additionally, site-related multimedia content in the form of videos and photographs can be transmitted to keep higher command updated with the relief developments.

E. NFC
NFC (Near Field Communication) is an RFID-based short-range wireless communication technology. It defines a set of standards for carrying out radio communication between smartphones and other portable devices by pointing, touching or bringing them close within a distance of few centimeters [36], [41]. The technology used by NFC, though, is similar, but unlike RFID, which is business driven and focuses mainly on items tracking, offers a wide variety of usage [41]. NFC operates at 13.56 MHz with variable data rates of 106–424 kbps. It works in the range of 0.2m with proximity distance of 4cm or fewer [41]. In an emergency scenario like a battlefield, where time remains a crucial factor, NFC may help avoid overwhelming of the medics by transferring victim's data from electronic triage tag to the proximity device without indulging in prior connection setup.

F. LoRa
LoRa (the acronym for Long Range) is a low-powered Wide Area Network technology proposed by LoRa Alliance and is intended for the wireless devices operating in local, regional or national networks. This standard emphasizes on secure bi-directional communication, mobility and localization services using 'star-of-stars' topology architecture, where gateway acts as a transparent bridge between end-devices and network server in the backend using IP networks. Data rates can range from 0.3 kbps to 50 kbps. Moreover, adaptive data rate (ADR) scheme is used to maximize battery life, network capacity, and data ranges. Its special feature facilitates securing of confidential personal data using several layers of encryption that includes Unique Network Key (EUI64) for ensuring application and network level security as well as Device Specific Key (EUI128) [42]–[44]. LoRa based devices, such as motes equipped with additional layers of encryption, may be effectively utilized in a disaster for privacy and security purposes.

G. 3G/4G
3G/4G standards, defined by International Telecommunications Union, are the third/fourth generation cellular standards for high-throughput data services on mobile phones. The mobile telephony standards have evolved from the first generation since 1980 to the fourth generation in 2009 [45], [46]. Interested readers are referred to [45] for getting background on cellular standards and their respective features. 3G is the evolution of 2G to cater for the demands of the high-speed data transfer and bandwidth-hungry multimedia applications. The data rate achieved with 3G is up to 2 Mbps. 4G is the latest global standard, supporting data rates up to 100 Mbps, suitable for transfer of highly rich multimedia applications [45], [46]. With cellular networks increasingly becoming ubiquitous in nature [47], 3G/4G becomes the most popular option, subject to the safe operation of the terrestrial infrastructure, during emergency response.

H. UWB
Any radio technology communication having usage of transmission bandwidth greater than the minimum of the two bandwidths: 500 MHz or 20 percent of the arithmetic center frequency, as per Federal Communications Commission (FCC), comes under the definition of Ultra Wide Band (UWB) [35], [37], [48]. Considering the definition and regulations outlined by FCC, UWB does not refer to a technology, and instead, it is only an available spectrum for license-free use [48]. ECMA 368 is the UWB standard and achieves a throughput of 480 Mbps. EWB supports Star topology within a range of 10 meters [35], [37].

I. INFRARED
Infrared is used to carry out short-range line-of-sight wireless communication. The frequency of the infrared lies below the visible light in the electromagnetic spectrum. Infrared allows devices to transfer data in a full-duplex mode [35], [49]. Laptops, cameras, mobile phones and other devices use infrared for communicating in "last one meter" based upon point-and-shoot principle. The prominent characteristics of infrared communication are the physically secure transfer of data and a remarkably low bit error rate which in turn makes it efficient [35]. The transfer rate of infrared is around 4 Mbps [35].

J. RFID
In Radio Frequency Identification (RFID), electromagnetic fields are used over a short range for automatic collection of data in order to identify, interrogate and track tags attached to the entities [50]. Passive and Active tags are the two classifications of RFID tags. Passive tag collects energy from the electromagnetic waves of the interrogator/reader to activate itself and acts as a passive transponder, whereas active tag contains a power source and may successfully respond to the reader at a distance of 100 meters [50]. RFID systems can also be classified into Low Frequency (LF, 125–134 kHz), High Frequency (HF, 13.56 MHz) Ultra High Frequency (UHF, 860–960 MHz) and Microwave systems (2.4 GHz and 5.8 GHz) on the basis of frequency band they operate in. RFID achieves data rate up to 100 kbps within its coverage range of 100 meters [37].

K. SATELLITE
Satellite technology, since its launch in 1957, has made significant technical innovations and advancements over the years and nowadays finds its usage in diverse applications such as telecommunication, military intelligence, weather forecast, navigation, just to name a few [51]. Satellite technology consists of two parts: a space segment and a ground segment. The space segment consists of the satellite in the air while the ground segment is the intended ground receiving station connected further to a terrestrial network [51], [52]. Inexpensive solutions like VSAT (Very Small Aperture Terminal) satellite [52] with ubiquitous coverage exist, which makes

satellite an economically feasible option. However, it may suffer from low throughput due to high latency as well as variations in Round Trip Time (RTT) [52]. Considering the time required to set up a new communication network from the scratch, especially at a remote location, satellite technology requiring only first time setup seems better alternative in a time constrained emergency scenario.

L. OPTICAL WIRELESS

Optical wireless, also known as Li-Fi, is an emerging light based technology envisioned to offload indoor RF hotspots [53]. The proliferation of wireless devices operating in the already crowded RF spectrum has driven telecommunication companies to look for more capacity. In this context, Li-Fi operating as standalone or hybrid with RF routers would prove to be a capacity booster. Operating in the unregulated optical spectrum incurring no licensing cost, it offers a cost-effective solution. Also, since its operation is confined to indoor areas, Li-Fi does not suffer from signal attenuation due to atmospheric and weather effects [53]. The inability of light to pass through opaque objects offers Li-Fi an added advantage of bandwidth reuse as compared to RF. This also makes it less vulnerable against any malicious attempt [53]. However, it also associates a drawback with Li-Fi enabled devices in the form of limited mobility [54]. Optical wireless, including free space optical, is envisaged to find its usage in diverse applications such as optical interconnects, backhaul links and even satellite communications [55].

III. WIRELESS BASED EMERGENCY RESPONSE SYSTEMS

The introduction of wireless technologies for relief activities has already paid the dividends in the form of improved and coordinated response. The ratio of people who previously used to succumb to their injuries in a calamity due to lack or out of reach of proper healthcare facilities has drastically reduced. In Crete only, an island of Greece, statistics show improvement by 65% [13]. With the advent of high-speed wireless technologies such as 802.11n, 4G and preparations for 5G rollout in 2020 well on its way, the prospects of wireless based emergency response system are envisaged to surpass conventional emergency systems as a first choice system. However, to reach such an optimistic level requires detailed analysis of these systems. Since a system designed keeping in view some specific circumstances may underperform or become inapt for other scenarios, we consider it necessary to study the scope and requirements of systems targeted to operate in diverse types of circumstances. To proceed further, we divide emergency circumstances into four major categories namely natural disaster, terrorism event, battlefield scenario, and patient monitoring. We present the scope and requirements of emergency systems aimed for these circumstances in the ensuing paragraphs and subsequently, we comprehensively discuss some key contemporary emergency response systems.

Systems for Natural Disasters: A natural disaster may generally be characterized by the destruction on a very large scale due to some natural process resulting in colossal loss of life, injury to hundreds of thousands of people and total collapse of the communication infrastructure. Furthermore, roads destruction/blockage may leave disaster-affected people scattered or in isolation from rest of the world. Hurricane Katrina, Pakistan earthquake 2005 and tsunami are few examples in this regard. Hence, an emergency system designed to operate in post-natural disaster scenario should primarily enable public safety agencies to operate independently of the terrestrial infrastructure. It should aid first responders for patient tracking in a sparse environment while being resilient enough to withstand the aftershocks of the disaster. Since rescue mission in a natural disaster usually involves teams from other countries as well, having diverse specifications and standards, the emergency system should provide a universal platform for interoperability. Additionally, it should be suitable to handle bandwidth intensive content that may be utilized to project a complete picture of the mission for the strategic commanders.

Systems for Terrorism Events: A terrorism event is defined as a human act of intimidation against people to achieve preset aims. As opposed to natural disaster, it generally remains confined to a much smaller scale with communication infrastructure around safe and operable, nevertheless having few exceptions such as 9/11. APS Peshawar attack is one such example that took place in Pakistan in 2014. Emergency systems targeted for these types of events hence should mainly allow first responders to triage victims rapidly followed by pre-hospital health care in ambulances to preclude critical patients dying of their wounds. Terrestrial infrastructure with traditional routing protocols may be utilized for communication amongst on-site rescue personnel.

Systems for Battlefield Scenario: Besides their own survival, rescue personnel are faced with the tough task of rescuing injured persons in a time critical hostile environment in the battlefield. The situation further exacerbates with the communication system breakdown, mobility limitation as well as structural damage. Accordingly, it requires an emergency system leveraging a rapidly deployable network that could function independently for communication purpose, if required. In addition to this, it should aim to automate patient tracking process, while having a mechanism to sort out victims requiring immediate help.

Systems for Patient Monitoring: Patients suffering from a chronic disease such as dementia are required to be monitored regularly to keep their health parameters in check as well as deliver health expert's opinion when required. Therefore, systems designed for this purpose should be able to record health parameters of the patient and update the concerned health experts regarding the same at regular intervals. The system should also host some communication module to receive expert's opinion in the form of textual or visual messages. Since the system is to continually record the parameters of a mobile patient, the size and specifications of the systems become critical and mandate them to be wearable with a portable size.

Having discussed the scope and requirements of emergency systems aimed to manage emergency related activities in different scenarios, we next deliberate upon various wireless emergency response systems that have been designed, prototyped or operational over the years. Some of these systems focus on providing a reliable multimedia communication network when regular communication infrastructure is uprooted/congested while others aim to extend health experts' opinion telemetrically at the incident site for saving victims' life. On the basis of the key design goal, wireless emergency systems can be broadly categorized into three types (discussed in detail later); Multimedia-Enabled Networks and Systems, Disaster Recovery & Management Networks and Systems, and Real-time & End-to-End Patient Monitoring Networks and Systems. On the other hand, wireless systems can be placed under the following three broad categories on the basis of the technology employed. (1) Cellular Networks [16], [56]; (2) Ad-hoc Mesh Networks [8], [12]–[14], [17], [19], [20], [57]; and (3) Hybrid Networks [11], [58]. Cellular networks make use of existing cellular communication infrastructure to relay data across WAN [19]. Ad-hoc mesh networks are the self-managing and self-organizing networks, formed by on-site wireless sensors deployed by medics, to accomplish rescue and relief tasks [19]. Hybrid networks make use of satellite technology in combination with the terrestrial infrastructure to execute emergency-related activities. The consolidated data of miscellaneous wireless systems has been summarized in Table 3.

A. MULTIMEDIA-ENABLED NETWORKS AND SYSTEMS

The updates from an incident site in the form of still photographs and good quality videos keep the high echelon updated of the relief activities and plays a crucial role in efficient decision making. Unfortunately, legacy systems have scarce capacity to transfer such bandwidth intensive content. Evolution of wireless technologies to offer high throughput enables wireless systems to suitably address this limitation. In this regard, DUMBONET [9] and DistressNet [10] are the two prominent wireless systems with the objective of providing multimedia communication links between disaster site and the command headquarters. DUMBONET, a rapidly deployable single mobile ad-hoc network (MANET), supports incident-site related multimedia content to portray a complete picture to high command, while DistressNet integrates disparate wireless networks (802.11, 802.15.4 and IPv6) to offer multimedia connectivity between dispersed calamity sites and Command and Control (C2) Center. SALICE (Satellite-Assisted Localization and Communication Systems for Emergency Services) [11] is a hybrid system designed with an objective to provide global coverage of the calamity-ridden area through the integration of space and terrestrial segments. In this regard, SALICE employs space segments to carry out long haul communications while terrestrial networks are utilized for on-site communication. All these systems are described in detail in the subsequent paragraphs.

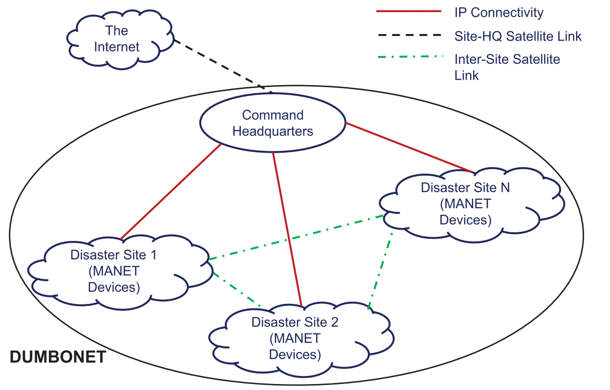

FIGURE 2. **DUMBONET architecture (figure adapted from [9]).**

1) DUMBONET

DUMBONET [9], specifically designed to cater bandwidth-hungry multimedia applications, aims to provide a communication network for inter-agency coordination and collaboration purpose in search-and-rescue (SAR) activities. Figure 2 illustrates the DUMBONET architecture where disaster sites are interconnected with each other to form a MANET. Individual disaster sites are equipped further to with MANET devices like mobile nodes, end systems, and link capacities. A node on the network can establish a communication link with other nodes at the same site, a peering site, a remote site or a command headquarters even through Internet. On the other hand, command headquarters can observe all under command sites and communicate either to a specific site or all sites simultaneously through broadcasts.

In DUMBONET, each rescuer possesses Wi-Fi enabled mobile devices, operating in the peer-to-peer mode to form MANET, each running the Optimized Link State Routing (OLSR) Protocol. The connectivity among disaster sites and with the command headquarters is maintained through satellite links thus reducing reliance on the terrestrial communication infrastructure. A Virtual Private Network (VPN) is established to hide the heterogeneity of the underlying architecture. After making its debut in a simulated environment in Phuket in 2006, a tsunami struck area in Thailand (for details and results of the experiment, please refer to [9]), DUMBONET III, its latest version released in 2011, was deployed in real environments of Cyclone Nargis Myanmar, 2008 and Nepal Earthquake, 2015 with encouraging performances [59]. The primary concerns and research issues regarding DUMBONET include provisioning of QoS and maintenance of MANET connectivity in catastrophe areas [9].

2) DistressNet

DistressNet, built around wireless ad-hoc sensor networks, aims to enhance situational awareness in a large scale calamity ridden area [10]. It caters rescue personnel's mobility and maintains connectivity between dispersed sites and

TABLE 3. Consolidated data of wireless emergency systems.

Emergency Response System	Purpose	Type	Technologies Employed		Routing	Applications in Emergency Response	Reference for Details & Latest Update
			BAN/LAN	WAN			
DUMBONET [9]	Multimedia-Enabled Networks and Systems	MANET	Wi-Fi	Satellite	OLSR	Search and Rescue (SAR), Identification of Victims	DUMBONET v 4.0 released in 2011 [59]
DistressNet [10]		WMN	802.15.4	802.11	On-demand & Delay Tolerant Routing	SAR, Situational Awareness	Fog computing provided for cloud services [72], [73]
SALICE [11]		Hybrid	802.15.4, 802.11	Satellite & Aerial Platforms	ODMRP	Global Coverage of Disaster Affected Area	Project expired in 2010 [74]
MIKoBOS [56]	Disaster Recovery & Management Networks and Systems	Cellular	Wi-Fi	GSM/GPRS /UMTS, TETRA & Satellite	Not Mentioned	Dynamic Workflow Management	Integration of fire dispatch system [75]
SAFIRE [62]		Conginitive Radio-based System	Cognitive Radio	Not Mentioned	Delay Tolerant Networking	Information Sharing between Frontline Responders	Not found
Hybrid System [58]		Hybrid	Wi-Fi & 802.11s	Satellite	HWMP	Mobile Communications	Not found
IoT-based System [29]		Cellular	Zigbee /GPRS	GPRS /Wi-Fi	Not Mentioned	Unbiased Decision Making	Not found
WiMesh [76]		Wireless Ad-hoc Mesh Network	Wi-Fi (802.11n)	Not Mentioned	OLSR with ELP [68], routing metric	Enhancing SAR	Documentation & downloads available at [76]
MyDisasterDroid [77]		Hosted on Android OS	Not Mentioned	Not Mentioned	Not Mentioned	Coordinating Rescue & Relief Operations	Details available at [78]
WIISARD [71]	Real-time & End-to-End Patient Monitoring Networks and Systems	Wireless Ad-hoc Mesh Network	Wi-Fi	Not Mentioned	AODV-based	Patients' Triage, Tracking & Health Status Monitoring	Measurement study [19]
ARTEMIS [20]			Wi-Fi	Satellite	ODMRP		Outdated link given in [79]
MEDiSN [17]			Not Mentioned	Not Mentioned	CTP		Details available at [80]
HYGEIAnet [13]			Not Mentioned	UMTS/GPRS	Not Mentioned		Details at [81]
AID-N [14]			802.15.4	802.11	Flows		Details available at [82]
Integrated System [16]		Cellular	WLAN Bubble	Satellite, 3G, 802.11/b	Not Mentioned		Not found
Patient Monitoring [8], [15]		Wireless Ad-hoc Mesh Network [8] Integrated WLAN & WiMAX [15]	802.15.4 [8] 802.11e, WLAN, 3G, WiMAX [15]	EVDO [8] WLAN APs, 3G [15]		Extending Emergency Telemedicine Services	Not found for [8], [15] utilized in [83]
MASCAL [70]	Enhancement of Hospital Response	Wireless Ad-hoc Mesh Network	802.11b, RFID	Not Mentioned		End-to-End Casualties Management, Staff & Equipment Tracking	Not found
AMON [84]	Health Monitoring of High-Risk Patients	Wearable Medical Monitor	Not-Mentioned	GSM		Health Monitoring of Chronic Patients	Details available at [85]
Serval BatPhone [63]	Emergency Telephony System	Wireless Ad-hoc Mesh Network	Wi-Fi	Not-Mentioned	BATMAN	Ad-hoc VoIP communication between rescue workers	Serval Mesh [86] Android app. on Google Play Store

C2 in a sparse environment. A single software architecture is provided, for all underlying heterogeneous networks (802.11, 802.15.4 and IPv6), having subtle features of sensing, localization, and communication. Different tiers of networks each having its defined role operate in cohesion in DistressNet. BodyNet operates at the lowest tier and encompasses low range 802.15.4 sensors worn by every rescue personnel in addition to the victims. Its main purpose is to monitor host's vital signs in addition to finding its geolocation. A team dedicated to a specific task e.g. SAR comes under the jurisdiction of TeamNet that encompasses BodyNets along with a few VehicleNets. Wireless routing, as well as Delay Tolerant Networking (DTN) functionalities, are provided by VehicleNet (the core network) to all elements of Distress. It also integrates 802.11 and 802.15.4 over IPv6. AreaNet includes immobile nodes, deployed at localized points to form 802.11 mesh networks, capable of delivering multimedia content. SenseNet is various specialized networks assigned with a specific task of sensing, tracking or monitoring.

DistressNet, an energy-efficient emergency response system, incorporates state-of-the-art features including distributed sensing, spectrum-aware multichannel MAC protocol and on-demand and delay-tolerant routing. To determine accurate locations in various dynamic and difficult environments of DistressNet and to support situational awareness, fuzzy estimation techniques are integrated with composable localization. All these aforementioned elements operate in harmony to provide first responders with an enhanced level of situational awareness necessary for prioritizing critical tasks in a rescue mission.

3) SALICE

SALICE [11], building on the idea that future emergency systems would consist of coexisting heterogeneous networks (satellite and terrestrial) [60], [61], advocates the use of a hybrid system for emergency response. It exploits satellite segments and aerial platforms in combination with terrestrial networks to guarantee global coverage of the emergency arena as well as enable cooperation of communication and navigation systems to complement each other. The architecture of SALICE consists of a reliable and robust NAV/COM network that enables communication amongst agencies taking part in the operation. A mobile master node (MMN), temporarily placed around the periphery of the affected area, utilizes satellite and transportable cellular network for inter/intra-agency communication purposes. Diversity techniques are exploited to help allow cooperation between satellite and terrestrial systems. A software defined radio based terminal, which is fully configurable and integrates capabilities of both navigation and communication, is an essential part of SALICE.

To render global coverage, SALICE defines two sub-networks namely Long Range Network (LRN) and Incident Area Network (IAN). LRN deals with long-haul communication connecting the incident area with external zones and mainly includes satellite and aerial platforms, while IAN allows communication within local and personal area jurisdiction and consists of IEEE 802.11 and IEEE 802.15.4 ad-hoc mesh networks.

B. DISASTER RECOVERY & MANAGEMENT NETWORKS AND SYSTEMS

Efficient resource allocation in an emergency response is one of the significant aspects that cannot be overlooked. The coordination between medics and incident commander enables the latter to rightly assess the urgency of the first responders' requirement and therefore efficiently allocate the resources in a dispersed environment. Accordingly, MIKoBOS [56] and SAFIRE [62] are proposed to synergize disaster recovery operation by allowing coordination among rescue personnel. MIKoBOS, an IP-based system, equips first responders, incident commanders, and command headquarters with role-tailored applications on heterogeneous devices for coordination purpose. On-site rescue parties make use of textual and visual messages to keep command headquarters aware of the whole scenario. MIKoBOS employs satellite technology in the case when fixed-infrastructure based networks such as GSM/GPRS get destroyed. Ahmed *et al.* propose SAFIRE, a cognitive-radio based system, which addresses intermittent connectivity of on-site wireless nodes. It operates in a distributed manner with all intelligence residing at the end-nodes and promises seamless and persistent connectivity among frontline responders. Li *et al.* [29] propose an IoT-based emergency system, which utilizes IoT infrastructure to collect real-time data from multiple departments and subsequently presents this data to the experts for reaching an unbiased and efficient decision in minimal time. The system employs clustering algorithms to discard the biased and isolated experts. WiMesh is a cost-effective as well as an energy-efficient system designed to enhance the post-calamity SAR operation in developing countries. It is a two-tier system; the first tier consists of wireless mesh nodes and provides the basic wireless backbone infrastructure, whereas the second tier comprises Wi-Fi-equipped Android mobile phones carried by rescue personnel. WiMesh server, attached to one of the wireless mesh nodes, offers several unique features such as authentication, maintenance of live status of rescue personnel, and a comprehensive network monitoring and logging tool which provides complete control over the mesh network. Finally, we discuss the first hardware based mesh telephony platform Serval BatPhone [63] which comprises Wi-Fi enabled Android smartphones (or a special BatPhone), working in 802.11 ad-hoc mode, and which are interconnected in a mesh topology using the BATMAN mesh routing protocol. The BatPhone has great potential for use in emergency relief activities since it works using just the portable BatPhones with absolutely no infrastructure or power requirements.

1) MIKoBOS

Meissner *et al.* [56] present design of IP-based MIKoBOS to provide reliable communication and improve coordination within/among public safety agencies. MIKoBOS has a multi-level software architecture as depicted in Figure 3. At the application layer, three indigenous applications namely

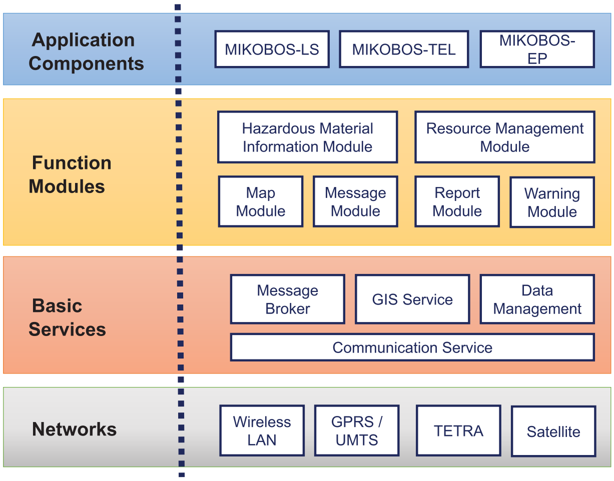

FIGURE 3. System Architecture of MIKoBOS (figure adapted from [56]).

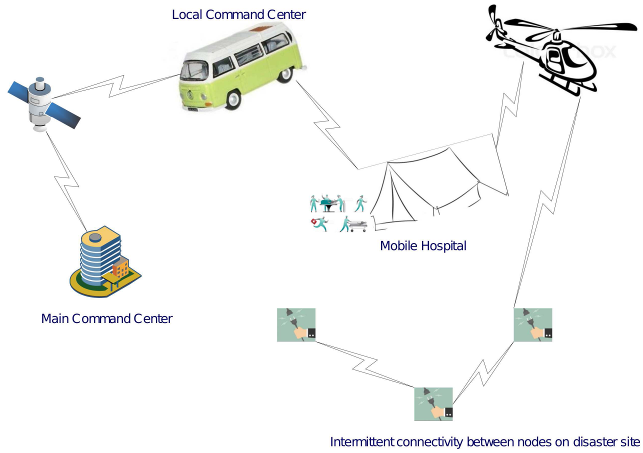

FIGURE 4. Intermittent behavior of wireless nodes at a calamity site (figure adapted from [62]) .

MIKoBOS-EP, MIKoBOS-TEL, and MIKoBOS-LS, hosted on role-tailored hardware platforms with custom functionalities, are developed for first responders, incident commanders and headquarters respectively. The networks layer is responsible for building a communication infrastructure for MIKoBOS. Frontline responders and incident commanders at the emergency site communicate via IEEE 802.11 Wireless LAN. Incident site-related data containing images and videos can be conveyed to the command headquarters through any of the three WAN communication standards: GSM/GPRS/UMTS-based public mobile networks, PSO-proprietary terrestrial trunked radio (TETRA), and satellite communication. Function Modules hire the services of Basic Services in order to perform some basic tasks such as data management and message negotiation. Communication service, a core component of MIKoBOS, aims to hide the heterogeneity of the system and provide a common interface for underlying networks and technologies. It deploys two application-layer communication protocols, built on top of TCP and UDP respectively, to mitigate the effects of underlying heterogeneous networks.

MIKoBOS performance was analyzed for two different types of messages (textual and visual) in different networks and results in [56] reveal that UDP-based protocol works way better than TCP-based protocol in delivering text messages over any type of WAN. In contrast, TCP-based protocol performs better in case of visual messages except in the case of satellite link due to prominent performance issues of TCP over high latency links [64], [65]. Further, MIKoBOS was tested to perform reasonably well even if no terrestrial based networks are available for WAN connectivity of incident site with command headquarters.

2) SAFIRE

SAFIRE is proposed to address the issue of the intermittent behavior of wireless nodes, mainly arising due to incompatible radios, at a calamity scene [62]. Figure 4 illustrates the communication links between different agencies participating in relief activities with emphasis on the intermittent connectivity of on-site network nodes. SAFIRE, a cognitive radio-based system, promises persistent information sharing among first responders in order for a disaster recovery operation to be coordinated and collaborated. SAFIRE works in a decentralized fashion with all the intelligence available at the end nodes. The core components of SAFIRE include the pub-sub module, routing/forwarding engine, radio module, and policy module.

Pub-sub module allows the exchange of information in publish-subscribe fashion without explicitly mentioning the source or the receiver. An application-based overlay establishes links between the communicating nodes, thus eliminating the need for the nodes to know the underlying topology. Routing/Forwarding engine learns the network topology and decides the best routes accordingly. In addition to this, it also stores packets in case an end-end connection does not exist between two nodes. Radio module deals with the spectrum sensing and the fine tuning of the cognitive radio, whereas policy module outlines the policies and standards regarding the operation of other modules.

3) IoT-BASED EMERGENCY RESPONSE SYSTEM

IoT defines a novel paradigm that connects every network-enabled object to the Internet. The idea behind IoT is to enable real-time information sharing amongst network connected ‘things’. The ‘things’ may include real world objects, virtual software agents or human beings. IoT may be used to enhance emergency response operation significantly, for instance, resources and personnel may be traced and tracked effectively using IoT in indoor as well as outdoor environments [66]. Similarly, IoT information infrastructure may be utilized for collaboration and coordination amongst multiple emergency departments participating in a disaster [67]. Building on these findings, Li *et al.* [29] advocate the use of IoT in emergent situations for efficient and unbiased decision making amongst experts usually geographically distributed around the globe. The authors proposes an IoT-based wireless emergency system considering the specific scenario of Beijing flood of 2012, but noted that such a system may be extended for other emergency circumstances. Data acquired through multiple resources using wireless sensors of IoT infrastructure is fed to a centralized controller, using Zigbee/LAN/WAN, that would process and prepare this data in the form of pie charts, histograms that would serve as situational reports to the experts [29]. Experts are taken on-board and interact through GPRS/Wi-Fi/WAN by the centralized controller in order to reach a consensus. Biased and isolated decisions are filtered out using clustering algorithms [29].

4) WiMesh

WiMesh is motivated by the fact that post-disaster SAR operation in developing countries like Pakistan is slow, inefficient and painfully mismanaged. The WiMesh system comprises of a two-tier architecture. The lower tier consists of portable multi-radio multi-channel wireless mesh nodes to create a rapidly deployable, auto-configuring and self-healing wireless backbone infrastructure, while the upper tier contains Wi-Fi enabled Android mobile phones, hosting WiMesh client software, carried by rescue personnel. The multi-hop capability of backbone mesh enables rescue personnel to exchange textual, visual as well as location-based messages amongst each other using Wi-Fi. The system also includes a monitoring and logging tool that provides elaborate control over the mesh network. The WiMesh system uses the OLSR protocol integrating the *Expected Link Performance* (ELP) [68] routing metric which provides better performance than conventional routing metrics.

A special node called WiMesh server, hosting WiMesh application server and OpenSIPs [69] VoIP server, provides many subtle features including authentication and maintenance of live status of rescue personnel, queuing messages and files for temporarily out-of-range personnel. Since the system is designed for developing countries, special emphasis is given to some key considerations like energy consumption and cost-effectiveness. For instance, the mesh nodes operate on dry batteries, which are further connected to solar panels in order to make the system operate independently of the power-grid in remote areas. Similarly, mesh network is built using inexpensive off-the-shelf equipment to make it cost-effective. Though WiMesh has been used mainly for relief and rehabilitation purposes in calamity-ridden areas of rural Baluchistan (Pakistan) but is envisaged to replace conventional communication system in remote and far-flung areas.

5) SERVAL BatPhone

The Serval BatPhone [63] is the first hardware-based practical mesh mobile telephony platform. The Serval BatPhone supplements infrastructure-based telephony systems with a device that is infrastructure-less, enabling cost-effective adoption of mobile telephony in rural and low economic regions. The BatPhone's independence from existing telephony infrastructure also makes it favorable to disaster relief networking. The Serval system comprises of Wi-Fi enabled Android smartphones (or the special BatPhones), working in 802.11 ad-hoc mode and interconnected in a mesh topology using the BATMAN mesh routing protocol. Mobile phones act as relays and enable multihop connectivity between mobiles located several hundred meters away. The Serval BatPhone has great potential for use in disaster relief situations. Users can create a mesh network on-the-fly with minimal configuration and can carry out VoIP communication over a couple of hundred meters or even more (depending on the users' dispersement) by leveraging the multihop mesh connectivity. Apart from the BatPhone, currently, an Android application named "*The Serval Mesh*" is also available online on the Google Play Store. One limitation of Serval is that since the wireless card installed in cell phones is relatively weak, so this network will have a very small coverage. Moreover, the batteries of these handheld devices will quickly drain as not only the phone has to cater to its own flows, it also has to process packets for other flows using this node in its multihop path. Finally, connectivity can be intermittent.

C. REAL-TIME & END-TO-END PATIENT MONITORING NETWORKS AND SYSTEMS

Pre-hospital health emergency care helps in saving precious lives, thus keeping death toll to a minimum, in a calamity as is evident from the statistics recorded at Crete. Moreover, it allows treatment units to prepare beforehand for any type of emergency. Paper-based triage and conventional patients tracking methods are time-consuming as well as error prone thus acting as show-stoppers in the timely delivery of pre-hospital care in a disaster. On the contrary, wireless systems equip victims with low power wireless sensors (e.g., pulse oximeter) to help first responders in performing electronic triage, the information which is then used for engaging health experts while in transit towards the hospital. Electronic triage tags, taking lesser time for triage, also allow first responders to serve more patients in short time. In fact, patient information, acquired in real time, is utilized for end-to-end health monitoring of the victims.

Various wireless systems have been designed serving the prime objective of real-time end-to-end patient monitoring systems. For instance, WIISARD (Wireless Internet Information System for Medical Responders in Disasters) [19] aims to automate patient tracking and assigning work chain and exploits responders' on-site frequent movements through Delay Tolerant Networking (DTN) techniques to improve data dissemination during a disaster. Carella and McGrath [20] propose ARTEMIS, Automated Remote Triage and Emergency Management Information System, to automate emergency response workflow in a time compressed battlefield scenario. It employs START (Simple Triage and Rapid Treatment) based medical algorithms to filter out casualties requiring immediate treatment. Furthermore, ad-hoc wireless networks enable ARTEMIS to operate regardless of terrestrial infrastructure at a disaster site.

MEDiSN [17], which stands for Medical Emergency Detection in Sensor Networks, promises improved quality of care through automation of health monitoring process. For this purpose, it records victim's vital statistics, using wireless sensors called as Patient Monitors (PMs), and seeks health experts' opinion afterward. MEDiSN achieves high levels of network utilization when evaluated in a simulated environment. HYGEIAnet [13], an emergency healthcare system operational at Crete (Greece), has led to substantial improvements in pre-hospital emergency cases that were successfully handled by medics without being taken to the hospitals.

MiTag (Medical Information Tag) based wireless sensor network [12] deploys miTag, a short range 802.15.4 compatible sensor, with an objective to automate patient tracking and thereafter provide real-time patient information to public safety agencies through an online portal. The pilot results during simulated multi-car accident show miTag sensors to be much more efficient than the traditional tracking methods.

AID-N (Advanced Health and Disaster Aid Network) [14], a hierarchical layered network model, equips on-site rescue personnel as well as victims with wireless sensors, known as Etag (electronic tag), which gauges the severity of the injuries through execution of simple and lightweight algorithms. Results show that AID-N performs better than traditional paper-based triage methods. Fry and Lenert [70] proposed MASCAL for efficient management of hospitals and emergency departments during a mass-casualty incident. It employs RFID technology for tracking patients, hospital staff and incorporates many key features including a backup server to handle network and system related contingencies. The role of telecommunication technologies in emergency response is investigated in [16], which proposes an integrated system architecture for coordinating emergency medical services in a disaster. It employs diverse types of wireless technologies including satellite technology to convey critical data collected by responders to the central database server. The detailed architecture of the proposed system is described in its respective subsection.

AMBULANCE [18], a handheld device, delivers pre-hospital health experts' opinion remotely at a disaster site through GSM links. It breaks the process of emergency e-health care into two separate modules namely mobile unit and consultation unit. The mobile unit deals with the patient's information collection and storage part, whilst consultation unit delivers specialist's opinion when required. All these aforementioned real-time and end-to-end patient monitoring systems are described in detail in this subsection.

1) WIISARD

WIISARD [71] manages overall emergency response activities—tracking victims, assigning critically injured victims to ambulances and finally, designating destination hospitals—thus considerably reducing the workload of first responders in large-scale disasters. To deal with expected large number of first responders' frequent movements in a mass-casualty event, WIISARD employs DTN techniques. Furthermore, all devices in WIISARD operate in the ad-hoc mode enabling WIISARD to operate in the devastated environments where terrestrial infrastructure usually gets destroyed. Role-tailored devices, provided to individual task teams, are categorized into three types; triage devices, mid-tier devices and command center. Entry and Medical teams keep RFID-based triage devices for triaging patients and managing their electronic medical record. Mid-tier devices incorporate the dual functionality of ambulances and hospital resources management as well as of triage devices, whereas command center acts as a hub for monitoring overall activities and managing available resources.

For evaluation purpose, WIISARD was deployed in a simulated earthquake environment at University of California, San Diego. The drill results presented in [19] show that network partitions usually get created during the rescue phase and prevent communication among peers of responder pairs. Furthermore, intermittency in the link connectivity is observed due to the mobility of the responders. However, DTN techniques may be employed to exploit mobility in order to improve data dissemination.

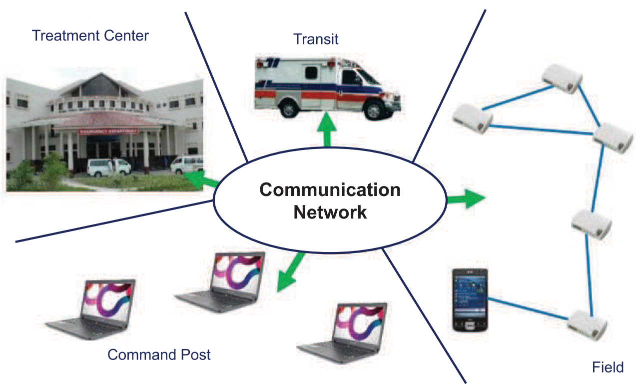

FIGURE 5. Information flow among ARTEMIS components (figure adapted from [20]).

2) ARTEMIS

ARTEMIS [20] aims to automate the emergency medical response in a time constrained battlefield scenario. Information flow sequence among ARTEMIS components is visualized in Figure 5. At the tactical level, the physiological and location data of all responders and casualties is continually monitored through wearable wireless sensors and subsequently disseminated to the strategic level that includes medics and commanders. To streamline the workload of the medics, medical algorithms classify the victims according to the nature and severity of their injuries and a concise summary of the same is dispatched to the medics through 802.11 ad-hoc networking. Casualties requiring immediate help are regularly monitored during transit and designated treatment center is updated regarding their status via cellular networks or vehicular-based satellites. Keeping in view the hostile environment in the battlefield, where terrestrial infrastructure is purposefully attacked, ARTEMIS uses ad-hoc satellite proxies for communicating information to the command centers and care units.

3) MEDiSN

MEDiSN [17] aims to automate the patient's health monitoring process, with an additional feature of enhanced security of patient's profile, during a mass casualty incident. MEDiSN comprises numerous PMs, Relay Points (RPs) and a Gateway as illustrated by Figure 6. PMs, which are motes equipped with sensors, monitor victim's vital statistics. These statistics are subsequently conveyed to the MEDiSN database server for instructions through a dedicated infrastructure mesh network made up of RPs. For this purpose, a Gateway acts as a communicator between MEDiSN server, connected to the Internet, and RPs. End-to-end encryption and authentication techniques are implemented to secure patients' data. Furthermore, retransmissions at every hop are ensured to add another layer to the data protection. The simulation results show that MEDiSN achieves high levels of network utilization and that collision and interference effects can be mitigated effectively using hop-by-hop retransmissions.

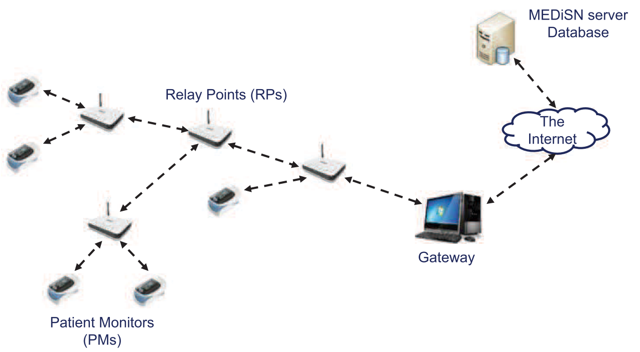

FIGURE 6. An overview of MEDiSN (figure adapted from [17]).

4) HYGEIAnet

HYGEIAnet [13] is an emergency electronic healthcare system designed and developed for Crete, an island of Greece, where the accident ratio triples during the touring season with 42% of the accidents involving the tourists. It is operational as Regional Healthcare Network at Crete and delivers e-healthcare services at various healthcare system levels including pre-hospital health emergency care. Cellular networks are utilized for extending pre-hospital emergency services whereas IEEE 802.11 is deployed for equipping hospitals and homes with remote patient monitoring services. The performance analysis of HYGEIAnet demonstrates that 65% of the total pre-hospital emergency cases are not required to be taken to the treatment units and can be successfully managed at the paramedics' level.

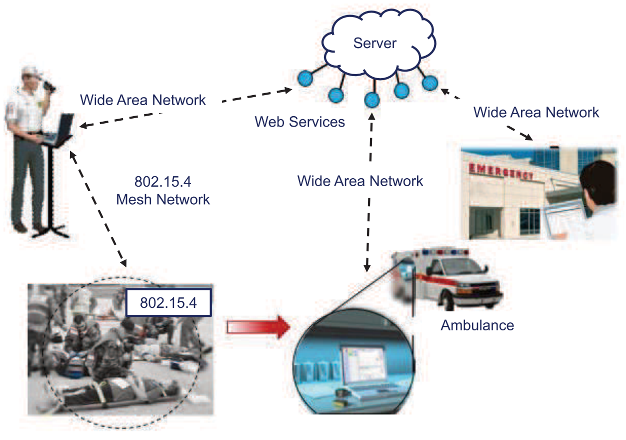

FIGURE 7. Pictorial view of real-time patient monitoring using miTag sensors (figure adapted from [12]).

5) MiTag WIRELESS SENSORS NETWORK

Gao *et al.* [12] present scalable miTag based wireless sensor network for automating patients' tracking process during emergency response at a disaster scene. The patients' tracking process, illustrated in Figure 7, starts with monitoring of casualties' vital signs using miTags followed by assigning ambulances and culminates at designating care units. MiTag is a short-range dynamically tunable 802.15.4 compatible sensor which collects patient's vital signs, location, and triage status. The members of the response team including first responders and paramedics may access and analyze real-time patient's data through an online web portal. To make the proposed system infrastructure-independent and suitable for areas highly affected by a disaster, WMN is created through repeater nodes dropped at strategic locations by responders while traversing the disaster-affected area, in order to enable communication among SAR team members. The pilot results of the proposed system during simulated multi-car traffic accident show that miTag sensors prove to be more accurate and efficient as compared to the traditional patient tracking methods. Furthermore, it generates comprehensive information regarding the patient's health status than the traditional methods thus greatly improving accuracy in patient diagnosis and treatment.

A similar work presented in [15] also equips casualties and medics with 802.15.4 based low-power short-range wireless motes for enhancing medical emergency services in a time critical environment during a catastrophe event. The sensors, working in an ad-hoc mode, collect vital signs of their bearers and dispatch this information to first responder's tablet device that displays it in an indigenously developed pre-hospital patient care software MICHAELS. MICHAELS writes the patient data back onto the mote to assist the medical staff when the patient is in transit towards the hospital. MICHAELS also transfers this data to a central medical database server through cellular standard EVDO. The real-time patient information can then be acquired by

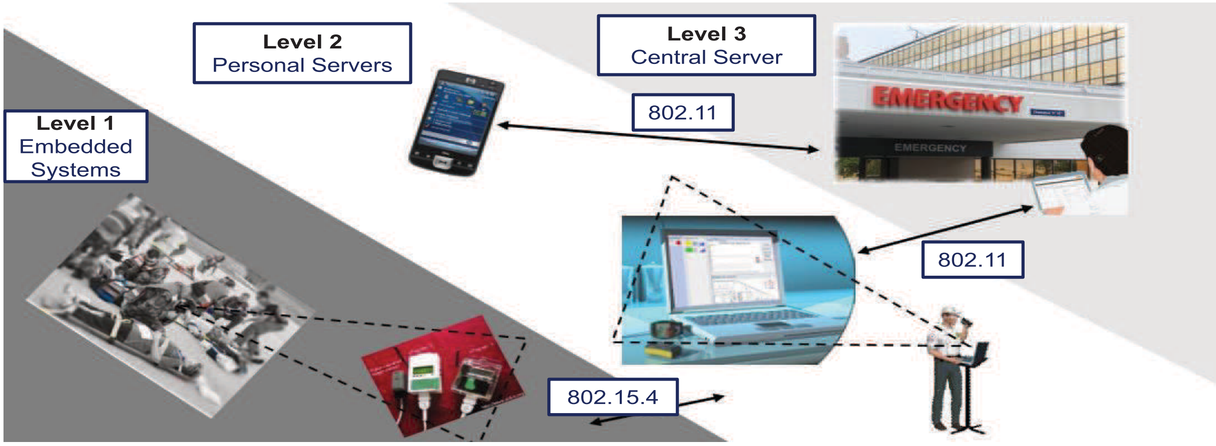

FIGURE 8. Hierarchy in AID-N architecture (figure adapted from [14]).

public safety agencies from the main server through web browsers.

Zhang *et al*. [8] propose the use of integrated WLAN and WiMAX networks for deployment of wireless telemedicine services. This healthcare service may be deployed in an emergency scenario to serve the critical patients remotely especially in rural areas.

6) AID-N

AID-N is a hierarchical layered network model developed for assisting public health agencies in a calamity [14]. The hierarchy of the AID-N architecture is depicted in Figure 8. At the bottom layer (Level 1), AIDN802.15.4 based embedded medical systems, known as ETag (electronic tag), constitute an ad-hoc mesh network and are deployed for collecting patient's vital signs. ETags execute simple and lightweight medical algorithms for determining severity status of the victim's health. The middle layer (Level 2) comprises patient monitoring system servers, also known as personal servers that connect to the Internet for transmitting the patients' data to the central server, which is at the top layer. The personal servers are the laptops or PDAs which use existing cellular networks infrastructure to communicate to the central server over the Internet. At the top layer (Level 3), the central server ERIC (Emergency Response Information Center) filters and disseminates the disaster-related information to respective public emergency departments in addition to the incident commander.

The evaluation of the subject system shows that AID-N performs much better than the traditional paper-based triage methods. Furthermore, the reduced burden of communication in AID-N ameliorates the efficiency of the rescue personnel.

7) MASCAL

Fry and Lenert [70] propose MASCAL as a solution for an effective and efficient response of the hospitals/treatment units in a mass casualty event. It employs 802.11b RFID for tracking of casualties, staff as well as equipment in a treatment unit. MASCAL generates the consolidated information acquired from multiple resources such as tag locational information, data from personal databases, registration applications, medical information servers and the US Navy's TACMEDCS triage application and displays in a customized graphical environment. It has many subtle features including registration procedure for incoming patients, brief turnover time in handing over a patient to the hospital staff and availability of a backup server to handle contingencies related to system and network failures.

8) INTEGRATED SYSTEM FOR MEDICAL EMERGENCY

Chan *et al*. [16] emphasize the role of telecommunication technologies in emergency response operation and proposed an integrated system to deliver coordinated emergency medical services during a disaster. The architecture of the proposed system is depicted in Figure 9, which employs new high-speed technologies instead of traditional ones.

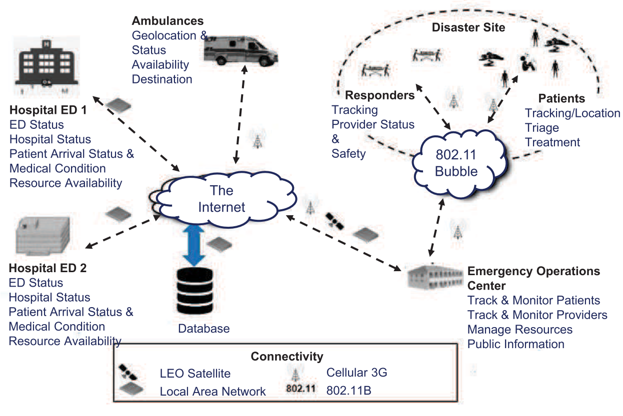

FIGURE 9. Architecture of Integrated System proposed by Chan *et al.* (figure adapted from [16]).

Victims' health status tagged with victims' respective locations is monitored electronically through wireless LAN bubble at the site. Cellular networks are utilized to relay information from responders' handheld device to the central server that contains real-time information on victims as well as all resources at hand, i.e., emergency departments (EDs), treatment centers, etc. Further, to make it resilient in case of severe infrastructure damage, alternate options such as satellite and 802.11b are exploited to update information database at the central server. Concerned authorities like incident managers, EDs and treatment centers acquire this up-to-date information to manage resources at their end efficiently. However, there are a few challenges associated with this system including concerns regarding the robustness of communication links in case of severe infrastructure damage, since the system mostly relies on infrastructure dependent communication and privacy/security of the patients' data.

9) AMBULANCE

AMBULANCE delivers expert pre-hospital medical care at a disaster scene [18]. As Figure 10 suggests, it has segregated the wireless emergency healthcare service in a disaster into two modules namely mobile unit (the disaster arena) and the consultation unit (hospital/care units). The mobile unit stores the patients' information on the hard disk while keeping the consultation unit (a Telemedicine Consultation Terminal) in picture for expert opinion. Mobile unit and consultation unit work mutually in the client-server mode using TCP/IP protocol over GSM.

IV. CHALLENGES IN REALIZING WIRELESS BASED EMERGENCY RESPONSE SYSTEMS

A number of challenges exist in realizing wireless based emergency systems due to inherent error-prone nature of the wireless medium and highly dynamic nature of emergency scenarios. The scarcity of critical resources such as wireless bandwidth and energy adds further to the complexity of the situation. We elaborate some notable challenges in the ensuing paragraphs. To simplify the organization of this Section, we have discussed interdependent or related challenges together under one heading. For instance, securing patient's data from unauthorized access logically requires that it is delivered only, once transmitted, to an authenticated and intended receiver. Therefore, authentication/trustworthiness of other devices is elucidated under privacy and security. Similarly, since QoS ensures that high priority data is given precedence over other traffic types, we have discussed prioritization of critical data with QoS. Moreover, routing protocols also need to provide an acceptable level of QoS without compromising on other design considerations like energy consumption, security, etc. Hence, issues related to routing protocols are also highlighted under QoS.

A. LIMITATIONS OF THE WIRELESS MEDIUM

Unlike the wired medium, the wireless medium is inherently unpredictable and link qualities vary over time due to multi-path propagation, signal fading, interference, and noise among other factors. Moreover, wireless protocols have some strategic limitations. For instance, the Carrier Sense Multiple Access (CSMA) mechanism of the popular IEEE 802.11 wireless technology suffers from the classic hidden [87] and exposed station [88] problems. These problems become even more severe for disaster communications networks that typically use multi-hop wireless connectivity (e.g. DUMBONET and DistressNet), causing unpredictable collisions and delays. Due to these factors, the effective available throughput over an end-to-end wireless multi-hop path becomes a tiny fraction of the theoretical limit.

B. INTEROPERABILITY

It is necessary to ensure that all the options and resources at hand must be efficiently utilized in case of crisis situations. These may include sharing of critical maps, situational reports, and status of medical coverage, etc. In such scenarios, the interoperability of all available devices plays an important role in achieving a coordinated response.

The presence of incompatible devices may serve as a bottleneck in the integration and interoperation of the system. To address this issue, there must exist a universal standard or a common platform, which should ensure the smooth interaction of disparate devices.

Edgeware has been introduced by Treglia *et al.* [89] for sharing of miscellaneous resources across disparate wireless devices and networks. It creates wireless grids to guarantee seamless interoperability and facilitate resource sharing across multiple devices and services.

C. RELIABILITY AND FAULT TOLERANCE

Reliability is a key aspect in determining the efficacy of a wireless network in an emergency situation. Reliability may encircle different aspects out of which ascertaining the trustworthiness of the patient monitoring system is the foremost. It is essential to identify the frequency of intervention by the sensor operator to achieve high reliability. Moreover, it is necessary to ensure that the system provides enough resolution to achieve quality remote diagnosis [90]. Similarly, fault-tolerance is essential for these systems as disaster situations imply several different types of failures due to the harsh terrain and difficult operating environment. Emergency response systems must be designed to be robust to faults, with particular attention to the problem of a single-point-of-failure that is common when using systems employing client-server architectures. Many emergency response systems [10], [76] employ ad-hoc or mesh routing protocols for communication which provide inherent resilience to faults.

D. DISCOVERY AND NAMING

In order to maximize the response in a disaster situation, the device discovery demands flexibility. That is, all the devices should be discoverable and should have application-centric names. Thus, a certain type of devices can mutually exchange information, which can be easily

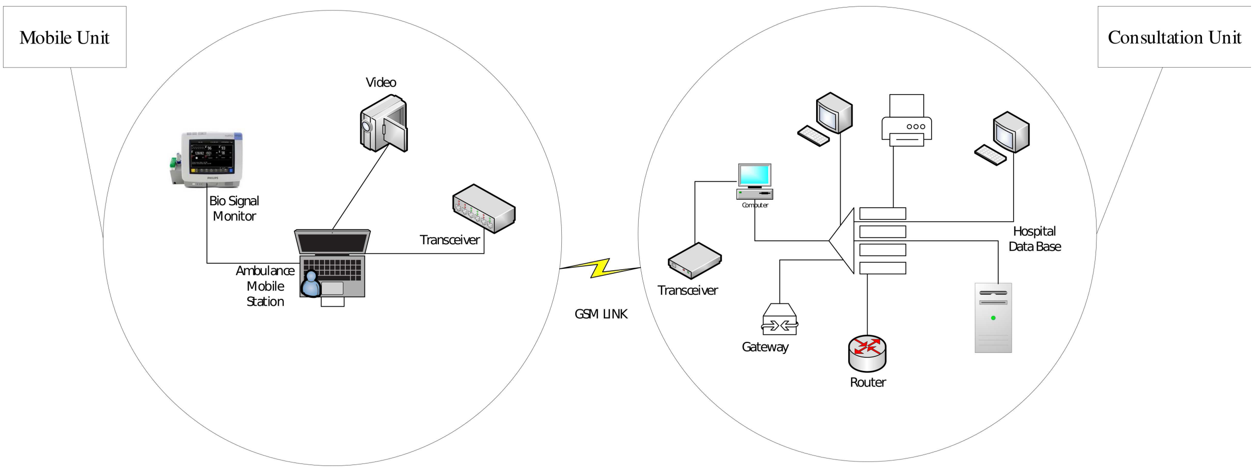

FIGURE 10. Use of GSM links to relay information between two modules of AMBULANCE (figure adapted from [18]).

interpreted by the operator due to the task-specific names assigned to the network nodes in addition to the network addresses. The discovery process has to be decentralized so that a single point of failure may be avoided [91].

E. PRIVACY AND SECURITY

Privacy is one of the major challenges in network design for handling emergency situations. It has special emphasis in healthcare services since the improper use of Electronic Health Records (EHR) can create devastating consequences. In order to ensure privacy, two requirements namely anonymity and unlinkability need to be fulfilled. Anonymity indicates that the patients' EHR should be kept confidential from other parties including insurance providers and management staff. However, healthcare experts and others should be authorized to access such information for the purpose of providing treatment and billing, whereas unlinkability refers that multiple EHRs should never be linked to a single patient.

While designing a network for use in emergency response, care must be taken so that its access control is role-based. Only authorized personnel/agencies are granted access to the confidential data such that the role and task of each agency have clear demarcations. Furthermore, the network topology in an emergency scenario may vary rapidly; hence the system should be adaptive to topological changes without compromising on security vulnerabilities [92], [93].

Channa and Ahmed [94] posit, during survey of various emergency response systems, that Mobile Ad-hoc Networks (MANETs) do not have any available security services and hence remain vulnerable in this regard. Therefore, services like access control, authentication and data integrity have been proposed for MANETs. In addition, although wireless sensor networks and mesh networks do offer authentication features for security purpose, lightweight cryptographic schemes can also be considered to improve upon these aspects [94].

Apart from securing EHR from unauthorized access, it is of great concern that the confidential data/information is delivered, when sent, to intended receiver(s) only. Hence, it becomes imperative to appropriately authenticate other devices prior to mutual communication. This can be done by using PKI (Public Key Infrastructure), which employs a pair of public and private cryptographic keys. However, PKIs assignment in an e-healthcare system becomes a daunting task since most of the times communication takes place among individual domains such as hospitals, clinics, ambulatory treatment centers, etc. A way forward for this is to have a common certification authority that should provide an identification and verification point for all the communicating agencies. One such example is RHIOs (Regional Health Information Organizations), employed by the United States of America (USA) in its e-healthcare system, provide an authentication interface among different communicating domains [92].

Hackers may exploit network loopholes to stall the smooth execution of emergency response. The most common attack to disrupt the network availability is DoS (Denial of Service) or DDoS (Distributed DoS), which can be implemented by flooding the network servers with fake authentication messages thus effectively choking the network. The effect of such type of attacks can be nullified by signal processing and various other techniques mentioned in [92].

F. RESOURCE SCARCITY

The emergency situation calls for an ad-hoc network that can be made operational quickly. These scenarios imply that the resources related to network infrastructure are essentially limited. This limitation can be in terms of power, bandwidth or size. The effects of resource limitation demand that judicious utilization of available options should be explored with maximum efficiency. Unlike their wired counterparts, wireless networks have energy limitations, especially for deployments in remote or disaster-struck areas, and inefficient routing and medium access approaches can quickly drain the battery, thereby minimizing network lifetime. Therefore, energy unavailability or scarcity implies that the designed systems must be energy-efficient. One approach is to use low-power components in the system which are smaller in size also ease mobility with an effort to minimize the bandwidth usage. Wearable sensor node SHIMMER is an example of such a system that consists of a built-in microcontroller with power consumption of 60 mW in active mode [95]. The small size of network components may be desired in several scenarios to make the network portable and rapidly deployable. These modest resources such as bandwidth, size, and power in wireless sensor networks may cause various design issues.

The wireless bandwidth is also a scarce resource which is further constrained in wireless multi-hop environments. Wireless protocols generally work on the principle of contention based access and due to collisions, interference and time-varying channel qualities, the available end-to-end bandwidth is not only limited but quite unpredictable as well. In order to alleviate these problems, appropriate design and software are required with a focus on these resource limitations.

G. QUALITY OF SERVICE

Assurance of QoS becomes extremely significant in emergency systems since we have constraints on the network capacity and the associated devices are low powered and generally, comply IEEE 802.15.4 standard [91]. QoS is necessary in order to prioritize critical data such as patient's vital signs or a message from a trapped firefighter over miscellaneous traffic and to ensure a certain performance threshold for some specific data. The performance metrics that quantify QoS of a data flow may include bit error rate, latency, jitter and packet loss, etc. [96], [97]. The highly dynamic nature of underlying network in emergency systems also demands robust routing protocols, which should be able to maintain a minimum level of QoS, while not violating other design considerations, including energy consumption and security. For instance, routing protocols may employ ad-hoc routing techniques to extend the effective communication range of the devices without compromising unacceptably on latency in an emergency environment where rescue personnel are frequently mobile [91].

The routing protocols may become vulnerable to external attacks and degrade QoS of an emergency system drastically. In general, common attacks on routing protocols include routing state corruption, wormholes, HELLO floods, blackholes, selective forwarding, Sybil attack and DoS [98]. Accordingly, a Secure Implicit Geographic Forwarding (SIGF) has been presented in [98] to ensure that routing protocols work efficiently and are not prone to vulnerabilities. Additionally, ADMR (Adaptive Demand-driven Multicast Routing) has also been tested in [99] for ad-hoc multicast routing on resource constrained sensor nodes.

H. LOCATION TRACKING

Various technological advancements that are now part and parcel of modern networks need to be available in case of wireless sensor networks in emergency response situations. The locations of various nodes in a network are always known in wired networks. During a disaster response, the knowledge of network nodes becomes extremely significant for the instant dispatch of medical care resources to the correct geo-location. In this context, the precise location of first responders as well as victims needs to be determined for efficient resource allocation. The nature of topography along with the location of the disaster scene, however, present major challenges in this regard. Assisted GPS technology [100], where GPS is integrated with a wireless network infrastructure, is a cost effective solution to know the geolocations with enhanced accuracy, coverage and availability as compared to standalone-GPS. An alternative to GPS approach is the RF-based location tracking [101] or ultrasound in the case when sky visibility is unclear for GPS device.

Peer-to-Peer Cooperative Positioning (P2P-CP) is another promising approach, suitable for disaster environments, which enables a GPS receiver that has a partial or totally obstructed Line-of-Sight (LoS) with the satellite, to cooperate with other stand-alone receivers to perform acquisition and compute its geo-location [102].

I. SCALABLE ARCHITECTURE

The emergency response at disaster site implies that the network will gradually scale up till the culmination of emergency handling activity. However, it presents a new challenge that to what limit is the network scalable. The situation demands that network architecture has to be scalable so that it can be extended to all the areas of the affected site. In general, unlike traditional networks, disaster communication networks typically follow a decentralized model which allows for greater scalability. However, decentralized systems are generally more complex than centralized systems and have the inherent classical problems of synchronization. The decentralization and scalability also present challenges for the design of appropriate routing protocols.

J. ENVIRONMENTAL CONDITIONS

The environmental conditions play a vital role in emergency response because the weather effects and other factors can affect the channel conditions, which would subsequently determine the throughput of the system being utilized. The network nodes/devices have to be waterproof so that they can withstand the influence of rain when deployed in an outdoor environment [15]. Another important environment consideration is the operating temperature range. Industrial-grade equipment, such as Gateworks Avila 2348-4 boards [103] support temperature range of $-40°$ to $+80°$, compared to off-the-shelf equipment, but cost more. The obstacles for wireless devices may also affect the network since they vary depending upon the dynamics of the disaster site.

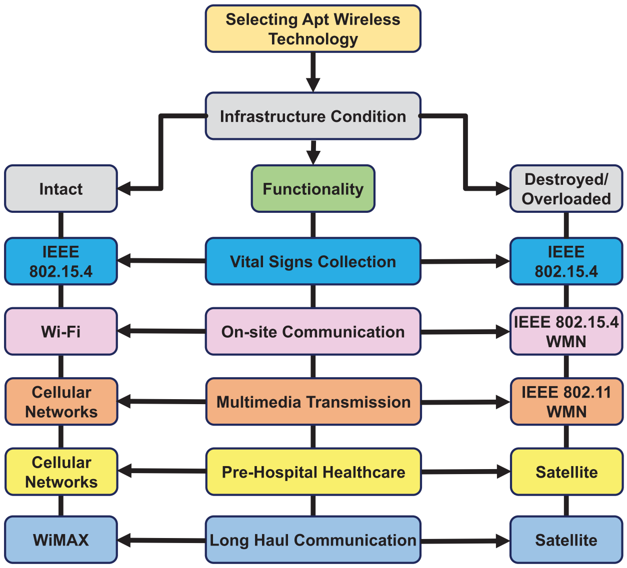

FIGURE 11. **Selection of suitable wireless technologies.**

V. APPROPRIATE WIRELESS TECHNOLOGIES FOR VARIOUS EMERGENCY RESPONSE FUNCTIONALITIES

The selection of an appropriate wireless technology for emergency response is greatly influenced by the nature of a calamity alongside the purpose intended to be fulfilled. To put it simply, it is about weighing the available options keeping in view first the extent of damage inflicted and subsequently the functionality required. In support of our argument, we consider two catastrophic events that happened in Pakistan in the last decade, namely, the terrorists' attack on Army Public School (APS) Peshawar 2014 and Earthquake 2005. We would notice that both had contrasting circumstances due to dissimilar level and type of implication and infrastructure destruction. The former was limited to the school with all the terrestrial infrastructure around safe and operable, while the latter was sparse with devastated infrastructure. On this basis, the two events may have had employed a disjoint set of technologies during emergency response. Thus, we outline general guidelines regarding wireless technology selection considering these two types of disparate circumstances and summarize these using illustrations in Figure 11 for a quick glance. To begin with, we segregate the functionality of emergency response into the following five phases:

- Collection of vital signs of casualties.
- Communication between frontline responders and incident commanders.
- Transmission of bandwidth-intensive incident related data in the form of high-resolution photos, videos or maps.
- Provision of pre-hospital care to the casualties when in transit to the designated treatment center.
- Communication between different sites and with headquarters.

The accomplishment of any emergency response operation heavily relies upon accurate execution of the first and foremost phase listed above. This activity usually initiates at the core (the most affected area) of the disaster site. Issues like little to no underlying infrastructure coupled with the power outage in a disaster affected area merit a wireless technology that consumes low power and could operate with little dependence on the infrastructure. IEEE 802.15.4 is the most suitable technology to be employed in such conditions since it offers low-speed communication even in an infrastructure-less environment, with low power consumption [104]. It is worth mentioning here that we recommend IEEE 802.15.4 for both types of circumstances as the terrestrial infrastructure at the arena may get congested soon due to the overwhelming number of persons impatiently inquiring about the safety of the persons concerned.

In case, if a disaster is confined to a small scale with no apparent damage to the infrastructure, Wi-Fi may be employed for information sharing between frontline responders and incident commanders. On the other hand, in case of a large-scale disaster with dispersed disaster sites, 802.15.4 Wireless Mesh Network (WMN), a 'self-managing network' would be a better choice to serve the purpose [105].

Cellular networks have become ubiquitous in nature and are offering data rates that are sufficient enough to transmit high-quality content. These networks may be effectively utilized for transmission of incident-site related multimedia files in order to render a complete picture to the top level managers. Additionally, pre-hospital emergency health services may also be extended over the existing mobile phone networks. On the contrary, 802.11 WMN may be employed for conveying incident site related data in case if the infrastructure is uprooted or overloaded in a disaster. For similar circumstances, real-time patient monitoring may be carried out through vehicular satellites. For the last phase, site-to-site and site-to-headquarters communication may take place over WiMAX in case where the infrastructure remains safe and operable, while satellite communication is a rapidly deployable and economically feasible option otherwise.

VI. PRACTICAL GUIDELINES FOR IMPLEMENTING EMERGENCY RESPONSE SYSTEMS IN DEVELOPING COUNTRIES

Developing countries generally face problems like the weak economy, untrained manpower and poor infrastructure, and which may become more prominent during disasters. A hefty portion of financial resources is expended on post-rehabilitation of disaster-affected people that proves to be an economic burden. Moreover, rural areas of the developing countries are still under-developed and have the scarce skilled manpower. Hence, these countries may not leverage wireless emergency systems with expensive proprietary devices requiring rigorous programming for configuration and installation. In this regard, we elaborate some of the aspects (based on the practical experience of one of the authors in rural Baluchistan, Pakistan) that need to be attributed importance at the time of deploying/designing wireless emergency system for developing countries. Furthermore, we also gauge all the systems surveyed against these aspects and present it in Table 4.

A. WIRELESS COVERAGE
The wireless coverage of wireless emergency systems in infrastructure-less environments makes them superior to conventional systems. Also, it defines the suitability of wireless system to a particular category of disaster scenario. For example, a natural disaster necessitates high wireless coverage (in hundreds of kilometers) system which could span across the wide swathes of the calamity-ridden area. Contrarily, coverage in few hundred of meters would be sufficient to monitor the patient suffering from any chronic disease.

B. COST EFFECTIVENESS
Mass-casualty incidents leave a severe impact on an already fragile economy of the developing or third-world countries. Governments usually require investing a colossal amount of money in post-disaster rehabilitation or survival of affected people, sometimes, in extreme weather. Hence, deploying expensive equipment in emergency systems in a developing country would not be an economically plausible option. Though inexpensive/cheap Commercial Off-The-Shelf (COTS) devices may require rigorous as well as cumbersome programming, these devices are easily affordable without causing an economic burden. For instance, DUMBONET employs satellite technology for long-haul communication that costs high in Pakistan [106]. On the other hand, DistressNet consists of inexpensive COTS equipment and therefore puts a low price tag on its deployment.

C. EQUIPMENT AVAILABILITY
Besides considering the cost aspect of the wireless system equipment, its availability in the local market is also critical for smooth operation of the emergency system. Procurement of sophisticated proprietary equipment from foreign vendors usually involves lengthy logistic procedures and may bring the relief activities to a halt. Moreover, provision of technical support for such equipment also consumes a significant amount of national exchequer. Accordingly, cost-effective readily available equipment should be focused upon while deploying a wireless system in developing countries.

D. PORTABILITY AND INSTALLATION
Time compressed dynamic emergency scenario merits wireless systems that are portable as well as quickly installable. The associated devices and other hardware should be able to operate in a plug and play fashion requiring no prior configuration. In developing countries, rescue personnel usually do not possess computer skills and hence the situation aggravates in case the wireless system is non-portable and takes long installation time. Furthermore, locating system experts and engineers especially in the rural areas of the developing countries is a tedious job. Therefore, portability and quick installation of a wireless system must not be overlooked when gauging viable options for developing countries.

E. DOCUMENTATION
Proper documentation, which may include operating instructions alongside interface connections, assists on-site rescue personnel in the smooth operation of the emergency system. In addition, troubleshooting guide citing possible troubleshooting actions vis-à-vis system unserviceability avoids any permanent damage to the equipment. Accordingly, a wireless system having good documentation should be given priority over other systems, when targeted to operate in developing countries.

VII. OPEN ISSUES & CURRENT RESEARCH AREAS
Although a number of challenges have been highlighted above that can be encountered while incorporating modern wireless technologies for emergency response services, there are some active issues that are a subject of further research. These issues have been partially addressed but are still too raw to be implemented on a big scale and are hampering the growth of this concept with regards to practical implementation. For instance, electronics circuits and wireless devices have to be more durable to withstand diverse environments. Multipath routing has to be optimized to make the network more fault tolerant. Location tracking of wireless nodes has brought various options but it is also a work in progress. The range of the network devices in an emergency response has to be enhanced in order to make it a more practical option. We discuss these issues in more detail next.

A. PHYSICAL CHARACTERISTICS OF SENSORS/ELECTRONIC CIRCUITS
In order to accomplish the successful implementation of emergency response networks, it is necessary that the physical characteristics of sensor devices exhibit durability and robustness for swift deployment at any site. The device circuitry should be durable in the sense that it should be able to withstand high temperatures, which may be experienced in case of firefighting. Similarly, the relief services at the site of a collapsed building should not be hampered in case of rainy weather due to the vulnerability of wireless devices in the network. Today, the tendency to use wireless technologies in emergency situations is less and walkie-talkie sets are preferred by rescue agencies due to these limitations.

B. MULTIPATH ROUTING
The dynamic nature of the disaster environment implies that the routing among various network nodes must be essentially multipath. On the contrary, single path routing may become a bottleneck in case of failure/congestion thus leading to inadequate response. The mobility of nodes is an inherent characteristic of emergency scenarios; so it becomes imperative to explore the area of multipath routing for further improvement [98].

C. LOCATION TRACKING
Various solutions for location tracking of devices have been proposed but none has been able to fully solve the issue yet. Existing solutions have employed the use of Assisted

TABLE 4. Evaluation of wireless emergency systems.

Emergency Response System	Wireless Coverage	Cost Effectiveness	Equipment Avialability	Portability & Installation	Documentation
DUMBONET [9]	Several hundred kilometers	Low due to satellite subscription	COTS	Portable & high installation time	Good
DistressNet [10]	Few hundred kilometers	High	Inexpensive COTS	Portable & average installation time	Good
SALICE [11]	Several hundred kilometers	Low due to satellite & aerial platforms	Combination of COTS & propriety	Portable & high installation time	Not available
MIKoBOS [56]	Several hundred kilometers	Low due to satellite & PSO-proprietary TETRA	Combination of COTS & proprietery	Portable & high installation time	Not available
SAFIRE [62]	Tens of kilometers	No information given	No information given	Portable & low installation time	Not available
Hybrid System [58]	Several hundred kilometers	Low due to satellite subscription	COTS	Portable & average installation time	Not available
IoT-based System [29]	Hundreds of kilometers	No information given	No information given	Portable & low installation time	Not available
WiMesh [76]	Tens of kilometers	High due to cheap equipment	COTS	Portable and very low installation time	Average
MyDisasterDroid [77]	Few hundred meters	High	COTS	Highly portable & very low installation time	Average
WIISARD [71]	Tens of kilometers	Average	Combination of COTS & proprietery	Portable & low installation time	Average
ARTEMIS [20]	Several hundred kilometers	Low due to satellite subscription	COTS	Highly portable & low installation time	Poor
MEDiSN [17]	Few kilometers	Average	Combination of COTS & proprietery	Portable & average installation time	Average
HYGEIAnet [13]	Thousands of kilometers	Not enough information	No information given	Not enough information	Not available
AID-N [14]	Few hundred kilometers	Average	Mostly Proprietery	Portable & low installation time	Good
MiTag [12]	Few hundred meters	High	COTS	Portable & low installation time	Not available
Integrated System [16]	Several hundred kilometers	Low due to satellite subscription	No information given	No information given	Not available
Patient Monitoring [8], [15]	Tens of kilometers	High	COTS	Portable & low installation time	Not available
MASCAL [70]	Few hundred kilometers	Average	Proprietery geolocation system	Portable & low installation time	Not available
AMON [84]	Tens of kilometers	High	COTS	Highly portable & very low installation time	Average
AMBULANCE [18]	Tens of kilometers	Average	COTS	Highly portable & very low installation time	Not available
Serval BatPhone [63]	Few Kilometers	Low	High if using Mobilephones Low if using Batphone	Highly portable & low installation time	Good

GPS, RF-based and by ultrasound means. Although all these technologies can be utilized in standalone mode, however, they have not been successfully integrated into tandem for utilization in disaster recovery situations [100].

D. MOBILITY SUPPORT

The scenarios for emergency response are diverse and limited mobility support has emerged as one of the reasons hampering its implementation on a larger scale for use in disaster scenarios. The nodes of the network would be mobile so it is necessary to incorporate improved mobility support to avoid network outages that may disrupt relief activities [77].

E. BIG CRISIS DATA ANALYTICS

Most of the emergency response systems described in Section III are categorized as real-time and end-to-end patient monitoring systems. To serve their main purpose, these systems maintain patients' information (personal and medical) database at the backend in order to disseminate requisite data to concerned departments when required. However, as the volume of data grows exponentially with increase in the number of patients, storage, as well as processing of this massive dataset, becomes a major challenge, especially in a large-scale disaster [107].

Big crisis data analytics address the abovementioned challenge since it employs big data techniques that are based on artificial intelligence, machine learning, and data analytics [107]. It uses 'data science' to explore valuable information from big data (referred to as the volume of data that becomes impossible to be processed by a single machine).

Additionally, future wireless emergency response systems would benefit heavily from big data. Destruction level, people movement pattern, as well as communication requirements in a disaster affected area, can be estimated through 'content analytics' of the big data [108]. Based on this information, first responders may prioritize their tasks accordingly. Moreover, deployment of wireless sensors and the selection of routes by the routing protocol can be made accordingly in order to eliminate the potential source of bottleneck [108]. However, integrating big data analytics with wireless emergency response systems is yet an unexplored area and hence a future research direction.

VIII. CONCLUSION

Although a vast amount of work has been done on designing wireless emergency response systems, the choice of the right architecture and technology for different emergency circumstances is far from clear. Furthermore, a number of potential pitfalls can subvert efforts towards deploying wireless-based emergency response systems. Based on a wide reading of the literature, and the practical deployment experience of one of the authors, we provide guidelines and highlight potential pitfalls that must be kept in mind during the choice of the appropriate emergency response system architecture and during deployment. After discussing several available wireless options for emergency response, a comprehensive comparison of the wireless-based emergency response technologies proposed in the literature is provided based on various considerations (including bandwidth, range, and throughput). We outline the scope and requirements of emergency systems targeted to operate in various types of catastrophe scenarios. We have also noted some open research areas in this field that require further exploration.

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