An Overview of Post-disaster Emergency Communication Systems in the Future Networks

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Abstract

The emerging fifth generation (5G) communication network is gaining tremendous attention from mobile network operators, regulators, and academia due to the provisions of network densification, ultra-low latency and improved spectral and energy efficiencies. However, post-disaster emergency management system (EMS), which nowadays predominantly depends on the wireless communication infrastructure, is significantly lagging behind in terms of innovation, standards, and investments. Since *5G vision* is the revolution of the telecommunication industry, provisions of efficiently handling EMS is expected to be distributed, autonomous, and resilient to the network vulnerabilities due to both man-made and natural disasters. In this paper, the 4G LTE approaches for typical post-disaster communication and their shortcomings will be discussed. We elaborate three typical post-disaster network scenarios when the network is congested, partly functional or completely isolated. The possible solution framework, for instance, Device-to-Device communication, drone-assisted communication, mobile ad hoc networks and Internet-of-Things, for post-disaster scenario will be discussed. Given that the spectrum allocation is critical for EMS, we assess the possible schemes for radio resource allocation specific for EMS in addition to the social responsibility of users in such critical situations.

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I. INTRODUCTION

The fifth-generation (5G) telecommunication is gaining enormous attention from the research community, regulators, service providers, and chipsets manufacturers because it promises ultra-low latency, very high spectral and energy efficiencies. The 5G system would be built along the lines of key techniques such as network densification, transmission over higher frequencies, i.e., mmWave, and massive machine-type communication (mMTC), which is the enabler of Internet-of-Things (IoT) that makes 5G a true heterogeneous network. However, neither the IoT nor the enhanced mobile broadband (eMBB) has been proposed considering the emergency management system (EMS), which, in cases of natural disasters, results in severe performance degradation of wireless networks due to equipments failure.

In post-disaster scenarios, such as flooding, hurricane and earthquakes, the network components are not able to perform to the maximum irrespective of the type of networks, i.e., distributed sensor network or macro cellular network. In recent hurricane Harvey in the US [1], FCC published that only one of the nineteen cell towers of Aransas County in Texas was functioning and 85% of cellular towers became offline in nearby Counties. In addition, during the 2011 Tsunami on the eastern coast of Japan caused by 9.0 magnitude earthquake, more than 6000 base stations (BSs) equipment were damaged. This caused heavy data and voice traffic on remaining BSs, which resulted in loss of communication services in vast areas and high rate of voice calls being blocked for four days after the earthquake.

The ultimate solution would be a wireless network specific for a disaster scenario that is independent of the existing broadband communication network. Such a wireless network solution may need dedicated hardware and frequency bands. Moreover, such network solutions should be highly energy efficient due to the limited power supply available during the post-disaster phase. However, it is exceptionally difficult to deploy such a network framework in the disaster area due to the time/energy constraints and higher implementation cost. Therefore, the wireless communication standards for public safety should be based on the commercial telecommunication standards to make them reliable, cost-effective and worldwide operable.

The state of the post-disaster wireless infrastructure is likely to be disparate depending on disaster types, e.g., earthquake, hurricane or terrorist activities. This prompts another question; can we have a single solution for all disaster scenarios? Certainly not in general, but we will definitely need a generalized solution to achieve the compatibility among user devices and interoperability among post-disaster communication technologies. This encourages stakeholders to design the disaster network solution which works within as many disaster types as possible. It is anticipated that the new network solutions must be compatible with the commercial network platforms. One of the techniques proposed by 3GPP (Rel-12 onwards) is the Device-to-Device (D2D) communication as a proximity-based service (ProSe) for both public safety and commercial use[1].

A typical cooperative network scenario and the flow of information during post-disaster are shown in Fig. 1. The cellular network, D2D communication, IoT, unmanned aerial vehicles (UAVs), mobile ad-hoc networks (MANETs) and satellite systems in cooperation would provide resilient post-disaster communication services. The users, emergency agencies and regulators use the voice and data services through the partially available cellular or cloud networks. As shown in Fig. 1, the isolated user(s) can use UAVs and satellite communication, where available, for information transmission.

Emergency communication requires a resilient and reliable network which is able to operate even in cases that network is partially dysfunctional. One of the essential KPIs is the level of resiliency a network can show, which can be expressed by the quality of resilience (QoR) metric. QoR is the network's ability to react in failure instances, such as software errors or link cuts, by rapidly re-routing traffic from failure affected paths to error-free paths, without being perceived by users. An intelligent EMS must incorporate recovery mechanisms responsible for failure detection, failure localization and failure recovery [2].

The mechanism of the cognitive vehicular network for emergency communication has been considered because the vehicles can be quickly driven into the affected area. Alternatively, a UAV-enabled aerial communications system can be deployed much faster in the disaster area [3].

To the best of our knowledge, no previous works actually identify the various network scenarios in disaster situation which makes it very difficult to classify the network problems and possible solutions. The contributions of the paper are as follows:

- We study the LTE approach and associated techniques that have been considered for post-

[1]https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=864

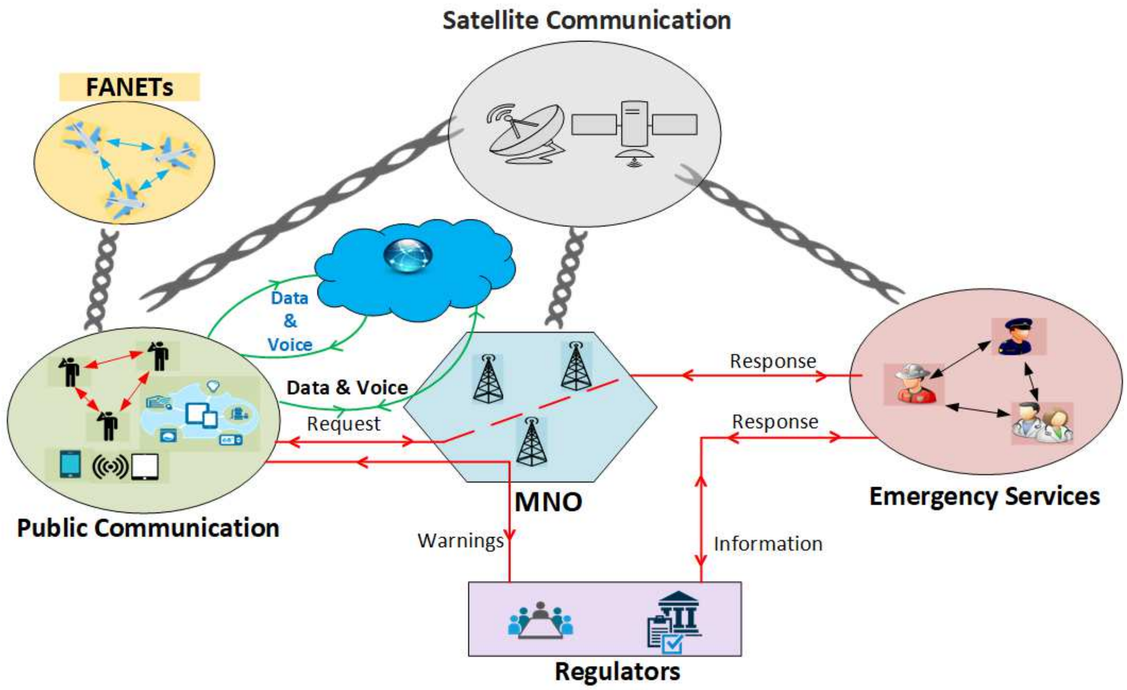

Fig. 1. A typical post-disaster communication framework.

disaster network scenario.

- We describe three typical post-disaster scenarios, i.e., congested, partially functional and isolated networks. The possible network solutions for each scenario will be presented.
- We discuss the spectrum allocation strategy for post-disaster scenario and possible 5G technologies, and users' and government responsibility to manage the post-disaster wireless network effectively.

II. LTE-A Approach for EMS

According to the Office of Communications (Ofcom), mobile devices account for over 60% of calls for 999 emergency services in the UK. This is due to the recent developments in wireless communication, which offer great potential for emergency services to operate even more efficiently and save additional lives. Moreover, wireless infrastructure is easy to deploy within very limited time and cost which makes it an attractive solution for EMS. Therefore, the traditional way of communication during post-disaster should be upgraded according to the constantly changing telecommunication technologies. One of such provisions in 3GPP LTE standard is the enhanced multimedia priority service (eMPS).

According to 3GPP TR 23.854[2], the eMPS functionality in LTE allows authorized users to obtain and maintain the radio resource and network components. These resources are provided during the eMPS session, i.e., the duration in which such functionality is enabled in the network, where priority treatment is applied in resource allocation on an end-to-end basis. Therefore, eMPS makes priority calls/sessions from mobile to LTE networks, mobile to fixed networks, and fixed to LTE networks when the network congestion occurs during post-disaster. One of the provisions in eMPS is the IP-based multimedia subsystem (IMS) services, which aim to optimally support the voice, video and data services over a wireless network with priority for authorized users during post-disaster.

Another network and service related enhancement in 3GPP Rel-11 is the multimedia emergency service (MMES), which utilizes the real-time session-based next-generation text, voice, and other multimedia between citizens and emergency authorities [4]. However, lack of signaling protocols to identify priority and authorization, message session relay protocols and industrial efforts to standardize the media format and protocols in which such services will be based have severely slowed down the deployment process.

Although LTE has been considered to be the candidate technology for post-disaster communications, the required level of QoR cannot be guaranteed due to its connectivity models and network topologies. Moreover, the highlighted techniques have been proposed considering the network scenario in which there is very high congestion in the system in case of an emergency situation. This is obviously an impressive way to handle high priority traffic in the system with the best possible QoS. However, there are many other post-disaster scenarios in which proposed techniques may not be working efficiently as presented in the next section.

III. Network Scenarios in EMS

The mobility pattern of users in the disaster scenario cannot be accurately predicted. Similarly, the traffic generation pattern of users in partially or fully-functioning communication network depends on nature of disaster and locations. Furthermore, there are possibilities of user(s) being

[2] https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=934

completely isolated from other users and network infrastructure. To generalize the proposed EMS solutions, we can thus identify and categorize three disaster network scenarios; congested network, partial network and isolated network.

The EMS approach responsible for handling such a variety of network scenarios for disaster cannot be managed manually. Therefore, the telecommunication infrastructure should be embedded with the auto-configuration and context-aware network algorithms. Such network scenarios are briefly discussed next.

A. Congested Network

The network congestion may occur when the mobile network components still function reasonably well during post-disaster. This results in the sharp increase in voice and data traffic causing network congestion, which ultimately brings the network into saturation point as shown in Fig. 2. Such a situation is very critical for new users because they cannot communicate both voice and data, which causes the connected users not likely to achieve required QoS. This initiates various problems to emergency service providers, e.g., locating the users and getting their real-time information. Moreover, there will be limited power supply from the national grid during the disaster events, e.g., earthquake and flooding, in which BSs are solely based on their own backup power. When BSs have to handle more traffic with less power supply, the lifetime of BSs is sharply reduced. During the Japan earthquake in 2011, there was 60 times the normal traffic volume which blocked approximately 95% of voice calls due to power outage problem [5].

Network congestion is also common when terrorist activities occur where population density is higher and users want to utilize the voice and data services to share information. In fact, mobile network infrastructure cannot be designed considering very high network traffic because it is expensive to increase the BSs and radio resources, which are significantly underused during the normal network condition. Therefore, it is critical to identify the urgent data/voice traffic, which requires low complexity resource optimization and machine learning algorithms on the BSs. The following two features possibly alleviate the congested network scenario.

1) Priority Groups: On the users side, the higher priority of voice over data is required due to large voice traffic during post-disaster as observed in natural disasters in Japan and the USA. The current LTE network and the proposed 5G network are all-IP-based infrastructures

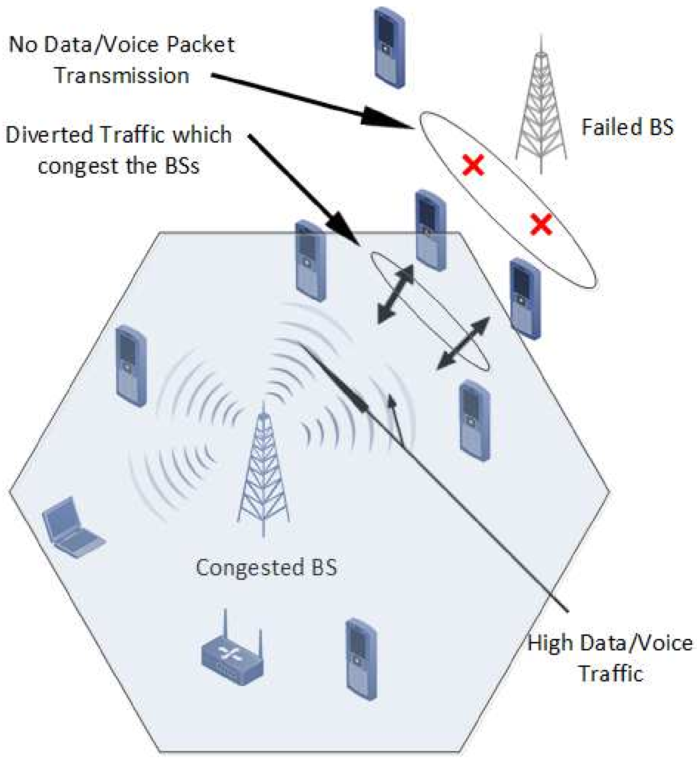

Fig. 2. A network congestion scenario when user traffic is higher and dysfunctional neighboring base stations.

to handle large volumes of data traffic where the voice is carried over the same radio and core networks through voice over LTE (VoLTE) upgrade. In such cases, prioritizing voice over data is very difficult to achieve. Therefore, a robust machine learning technique of prioritization and scheduling of resources in the transport network based on historic user traffic data is essential for future cellular systems to improve the QoS for voice and data services during post-disaster. The network slicing technique proposed for 5G, which creates multiple virtual networks within a single physical network, may provide a different level of QoS to the users.

On the emergency services side, priority should be given to the members of the emergency service providers. For instance, there is a mobile telecommunication privileged access scheme (MTPAS) in the UK since 2009 in which the mobile cells adjacent to the incident is identified and MPTAS is applied to those cells. If the resources are fully occupied by MPTAS users, other ordinary users' calls are rejected. Similarly, in the USA, wireless priority services (WPS) are available to national security and emergency preparedness (NS/EP) users which were implemented at the national level after the hurricane *Katrina*.

2) Priority Services: The optimal distribution of users traffic with various service priorities may lower the effect of network congestion for EMS. For instance, a higher priority can be given to the short messaging service (SMS) over voice or data communication. Such services are bandwidth-efficient and best-effort delivery which minimize the burden of post-disaster network management from traffic congestion. Another technique to lower the congestion is to embargo the voice and data for ordinary communication for a limited period of time immediately after the disaster, however, robust deep learning, e.g., *large scale unsupervised learning*, is needed to minimize the miss-detection by identifying the urgency of emerging traffic. Alternatively, by lowering the call-time or call-quality, a large number of users can connect to the communication system simultaneously. Therefore, an autonomous and resilient mechanism of EMS should be provisioned in next-generation wireless communication.

B. Partial Network

During the post-disaster scenario, it is possible that the network infrastructure, e.g., BSs or switching centers, are partially damaged. In such cases, a large number of users are likely to be disconnected whereas some users are still able to use the telecommunication networks for emergency services as shown in Fig. 3. Another scenario is that the users may be trapped inside the building or in the tunnel where they are not able to send and receive voice or data due to very poor radio signals. Moreover, the BSs may reduce the transmit power due to the power constraints when a disaster occurs. Therefore, the users in need to communicate should be able to connect to the nearest functional BSs either directly by increasing uplink transmit power or through the users in the vicinity. Since the first option is not optimal due to the power constraint, D2D and M2M communications are critically required to establish the multihop communication. Here, a low-complexity control signal exchange protocol to establish the multi-hop D2D/M2M is the absolute requirements.

1) Device-to-Device Communication: Although D2D communication is an integral technology of 5G framework which is considered as a tool to increase network connectivity and system throughput, its study for post-disaster communication scenario is rather limited. Therefore, it is necessary to revise the D2D communication architecture not only for commercial use but for also public protection and disaster relief (PPDR).

The D2D communication mode in a partially available network requires a lot of intelligence

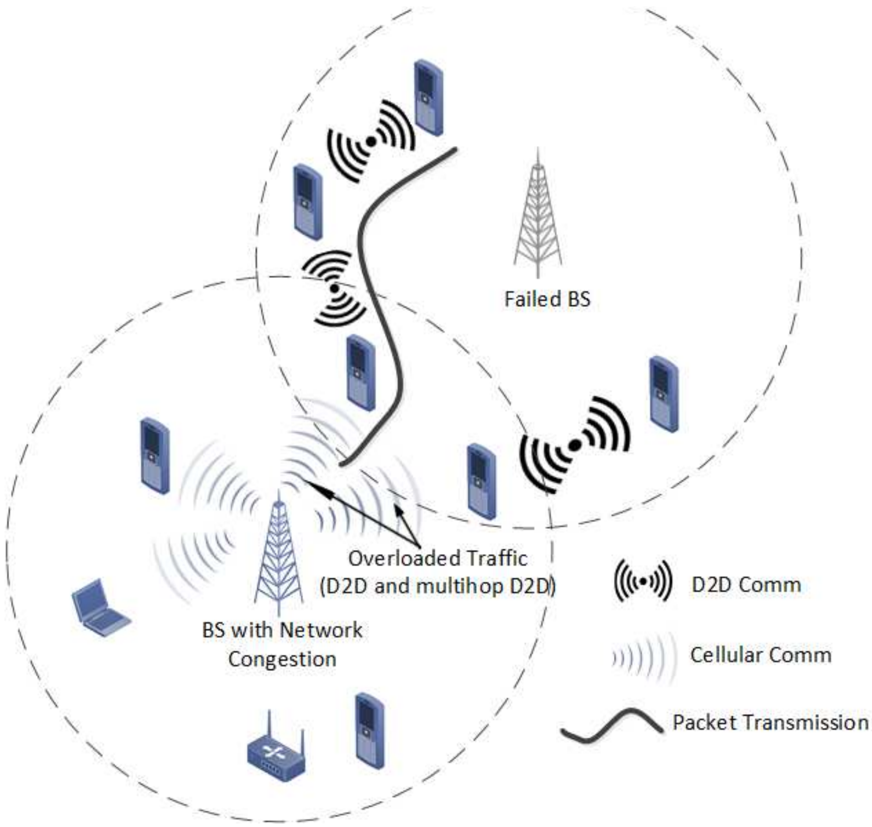

Fig. 3. A network scenario when users are partially connected to the network infrastructure for post-disaster communication.

in the user terminals and network components. The users access the nearest BS if any BS is still functional because the D2D mode needs other user devices in the cooperative mode and channel state information is needed between multiple devices. Therefore, users should continuously send and receive the control signals to both BS and the nearest possible D2D peers. Note that when a device processes a large number of control signals, the energy efficiency is significantly reduced. As a result, a new energy-efficient signaling protocol, resource allocation and optimization technique [6] will be needed to enable D2D mode for post-disaster communication.

Massive-MIMO enabled multi-beam technology is particularly applicable in high mobility D2D network to establish dynamic point-to-point links between devices. This ultimately improves the energy efficiency and reduces the interference on the D2D link due to the highly directional signal transmission to destination devices. However, novel message exchange techniques are needed in ProSe architecture to simplify the circuit complexity and energy consumption to make

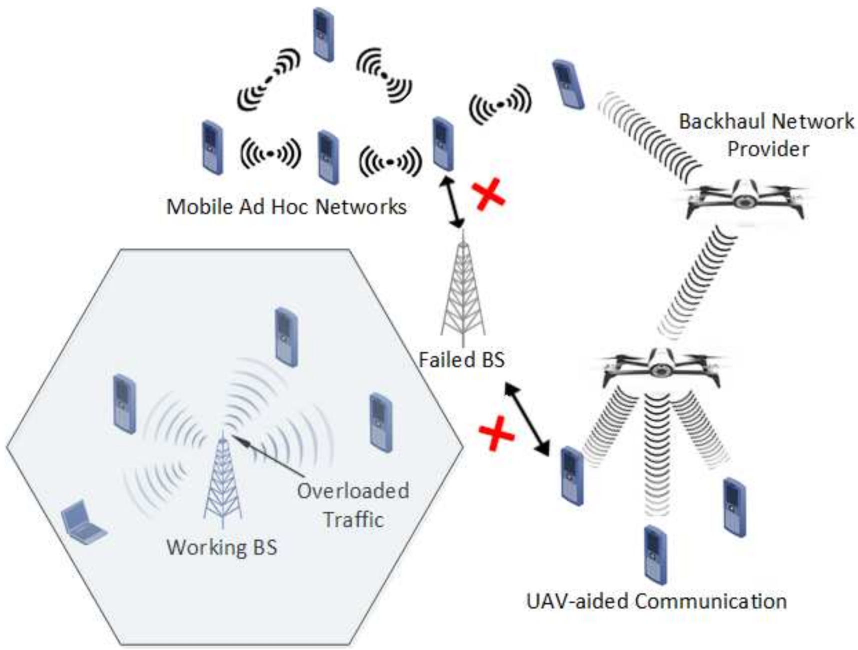

Fig. 4. A post-disaster network scenario where users are completely isolated from the base stations.

the user terminal efficient for beam-steering enabled D2D communication.

C. Isolated Network

This is the third possible post-disaster network scenario where the users are completely isolated due to the failure of backbone networks as shown in Fig. 4, where the packet loss rate is significantly higher. The user devices should be able to automatically switch to isolated mode when no control signal is received from the BSs for a specific period of time. Here, it is required to deploy a new network to provide temporary wireless coverage. Therefore, low-signaling location optimization for the newly deployed network and energy-efficient routing protocols are critical features for any proposed solution as mentioned below.

1) Mobile Ad-Hoc Networks: In such a network scenario, a multihop path needs to be created between the source terminal to the destination with a higher degree of reliability. A robust energy-efficient routing protocol must eventually be implemented to incorporate the battery capabilities in the user terminals.

The main advantage of establishing MANET is that it increases the redundancy of the source to destination path where the new path can be easily chosen when an existing path is broken or intermediate nodes are unable to communicate. On the other hand, the end-to-end delay between source and destination terminals is relatively higher. Moreover, the intermediate users may need to sacrifice the scarce energy for others which are not an ideal situation during post-disaster. The proposed 5G framework should consider such cases while designing distributed, autonomous and resilient multihop communication for EMS in order to preserve and ensure reliable communication among users.

2) Drone-assisted Communication: Drones, or UAVs, are able to significantly assist in post-disaster communication by acting as a flying BS as shown in Fig. 4. One of the advantages of implementing drones to replace dysfunctional BSs is that it is likely to exist direct line-of-sight communication between users and flying drones. This results in improvement on the channel propagation due to the low path-loss and minimum shadowing, which helps to improve the QoR required for emergency communication. Moreover, the drone trajectory can be optimized depending on the predicted traffic pattern and user distribution. The network of UAVs not only acts as a radio access network but also the backhaul network for D2D communication, MANETs and other isolated users. In a typical post-disaster scenarios, UAVs can be used as *UAV-assisted ubiquitous coverage* to enhance existing cellular communication, *UAV-assisted relaying* to connect distant users or user groups, and *UAV-assisted data collection* for periodic sensing of distributed IoT terminals.

In emergency communication, UAVs are also used for aerial views for observation and data gathering on the large-scale disaster zones which are hard to reach[3]. Moreover, they can be deployed as a temporary on-the-fly relay BSs during the post-disaster scenario. It is also suggested to deploy the drone ad-hoc network [7] to relay the users' data to the destination which is technically better than ground-based MANETs. One of the main drawbacks of deploying UAV is higher energy consumption for wireless communication and conducting flights. However, solar-powered UAVs can significantly mitigate the energy constraint problem.

The QoR analysis for three network scenarios is briefly discussed in Table I.

IV. Spectrum Allocation

During post-disaster and emergency situations, rapidly-deployable wireless network should be deployed until the existing wireless networks are repaired and come to its normal state.

[3]http://geoawesomeness.com/drones-fly-rescue/

TABLE I

A QoR ANALYSIS AND IMPROVEMENT TECHNIQUES FOR POST-DISASTER SCENARIOS.

Network Scenarios	**QoR Improvements Techniques to facilitate post-disaster communication**
Congested Network	• User traffic classification and prioritizing the user groups by analyzing received data • Advanced call and data buffering and queuing protocols to minimize connection loss • Machine learning based user grouping and association for efficient multicasting
Partially Connected Network	• Efficient switching protocol from the cellular to D2D communication mode and vice-versa • Multiple hop formation in a self-organized manner to the working base stations • Low signaling overhead and energy efficient distributed network protocols
Isolated Network	• Fast deployment of new network. e.g., MANET, UAVs, manually or enable multihop D2D communication • Optimal trajectory and altitude for UAVs, energy efficient signaling protocols for MANETs • Multiple routing paths to reach to the working base stations and the backhaul network

Such rapidly-deployable systems may be integrated with various technologies, e.g., cellular communication, Wi-Fi, satellite communication and MANETs. The spectrum allocation policy for commercial communication network may be difficult to implement in the disaster recovery phase. Therefore, a flexible but efficient spectrum allocation policy dedicated to post-disaster scenarios is essential.

A. Dedicated Band

It is important to establish dedicated frequency bands for PPDR services and applications in the context of increasing number of disasters in recent years. Such spectrum harmonization potentially increases the interoperability which ultimately helps to reduce the cost of equipments. It is also equally important for cross-border spectrum coordination, especially in EU and Asian countries, where one country may have many international borders. If different bands are used for PPDR, there will be severe interference among cross-border services in the already fragile post-disaster networks. It is obvious that next-generation PPDR must be built upon commercial network if no dedicated spectrum is available, which may not be able to sufficiently scale the requirements of post-disaster communication systems.

The spectrum in 400MHz and 700MHz have been planned for harmonized voice and broadband PPDR in many European countries, specified by European Telecommunications Standards Institute (ETSI). Both of them have extensive coverage range and excellent for voice and broadband services. Moreover, they have sufficient indoor coverage which may be helpful for users trapped inside the house in disaster situations. In EU countries, the 400MHz spectrum, typically 380-470MHz, are extensively considered to be available for broadband PPDR, direct mode operation and air-ground-air operations. The range of 380-385MHz for uplink and 390-395MHz for the downlink is proposed for PPDR. However, three Nordic countries, Sweden, Norway, and Finland proposed 700MHz band for the same purpose claiming 400MHz is insufficient to meet PPDR increased need for secure and robust broadband data. In addition, ITU-WRC, in 2015, recognized 694-894MHz as globally harmonized broadband-PPDR. In the future, we may face issues in frequency harmonization, for instance, in European borders. The mmWave communication for PPDR above 6GHz frequency has also been considered currently by the research community and industry [8].

B. ISM Band

The license-exempt bands or ISM bands, such as 2.4GHz and 5GHz can also be used for shared access for PPDR network to reduce the usage of the valuable sub-1GHz frequency band. Although the transmission range of this band is not as strong as a sub-1GHz band, it significantly helps to deploy the point-to-point links and wireless access points within limited time and cost by PPDR authorities. Since this band is not managed by licensing authority, the main issue is that there is no service level QoS guarantee to the end-users which is very critical for already vulnerable users in post-disaster networks. Furthermore, 868MHz ISM band, in which SigFox and LoRaWAN use for IoT network, would be an alternative for PPDR to partly solve the signal propagation issues in 2.4GHz and 5GHz bands.

Wi-Fi, which operates on ISM band, is a basic building block of today's wireless ecosystem. It has the potential to provide flexibility in post-disaster EMS. There has been significant progress on Wi-Fi development up until the recent 802.11ac standard, which supports 2.5Gbps data rate, thanks to the massive-MIMO and beamforming technologies. Since the majority of houses have a Wi-Fi access point (AP), the subset of APs which are still connected to the partially-functioning Internet during post-disaster could be made available by removing the Wi-Fi passwords for a limited duration. Alternatively, a guest network can be created by AP owners such that users and emergency service providers in need of communication are able to connect through Wi-Fi networks during post-disaster, as demonstrated in 2011 earthquake in north-east of Rome, Italy[4].

C. Spectrum Sharing

There is exceptionally higher traffic load whereas the network infrastructures critically underperform during the post-disaster phase. Even when new emergency communication systems are brought into the disaster area, the new spectrum is required to maintain minimum QoS for PPDR. Since the dedicated and ISM bands are not trivial solutions, highly acclaimed spectrum sharing system is an appropriate alternative.

The comprehensive telecommunication resource allocation plan for PPDR may not be possible due to the unpredictable nature of the disasters. For instance, the spectrum cannot be purchased in advance considering the disaster scenario due to the obvious reason of high cost of commercial spectrum. Let us consider the scenario where two mobile network operators (MNOs), i.e., *MNO1* and *MNO2*, are providing the services to users in a particular area under the *licensed shared access* approach. When a disaster occurs and *MNO1* infrastructure is dysfunctional, the users may not be able to communicate at all. When, at the same time, there is higher traffic in *MNO2*, the required spectrum can be leased or shared by *MNO2* from *MNO1* until *MNO1* is properly functional. Therefore, it is necessary to collaborate among government, regulators, MNOs, and manufacturers to enable spectrum sharing mechanism at least during post-disaster scenario within the proposed 5G framework.

V. Other 5G Technologies for EMS

The characteristics of the self-organized network (SON), i.e., self-configuration, self-optimization and self-healing, as described by 3GPP, are highly applicable for post-disaster EMS as well as disaster prediction by means of, for instance, inductive learning. The self-configuration feature reduces the manual work of deploying eNBs in the disaster area by enabling plug-and-play *automatic neighbor relations* feature. This feature is highly applicable when D2D communication and MANETs are deployed in the partial network scenario discussed above. The self-optimization entity helps to optimize the capacity, coverage and interference to maintain QoS and QoR which

[4]https://www.bbc.co.uk/news/technology-37186290

are very important in a disaster scenario. The mobility load balancing and handover features minimize the call drop rate in congested network scenario when a disaster occurs.

The evolution of IoT and big data brings remarkable potential to save lives in natural disasters. The emergency vehicles of police, fire, ambulance etc. can be equipped with M2M communication as an enabler of IoT [9]. Such connected vehicles help to autonomously coordinate among emergency agencies. Moreover, M2M communication dedicated to post-disaster can be engineered which is very applicable where emergency services cannot reach. Data collected from a self-organized network of distributed sensors located throughout the region are mined and machine learning technique is applied in order to predict the patterns of disasters for proactive measures, which can be multicasted to relevant users to save hundreds of lives within the disaster zone. For instance, the *public warning message* as point-to-multipoint broadcasting services has been considered for post-disaster communication under EU project *5G-Xcast* within the 5G framework. Another application of IoT could possibly be a wireless body area network for the efficient rescue operation.

The recent development and cost reduction on satellite technology brings tremendous possibility as an alternative communication system for PPDR because it increases the coverage, capacity, security and resilience to facilitate communication among users and the PPDR agents.

An overview of various wireless technologies within the 5G framework that are suitable for post-disaster EMS has been discussed in Table II.

A. Research Challenges

Since there is a lack of power supply during post-disaster, the proposed EMS network architecture should be highly energy efficient. In addition, when UAVs are to be deployed, optimal trajectory design, transmit power control and flying time optimization are equally challenging tasks. The future networks and 5G new radio (NR) specifications should be as compatible as possible for post-disaster wireless communication. Due to the power scarcity and OFDMA is not energy efficient, a new multiple access technique, e.g., NOMA, is possibly needed for post-disaster communication which needs further study. The mmWave, massive-MIMO and beamforming technologies are also equally applicable for user tracking and localization during the *golden hour* of post-disaster to save hundreds of lives.

TABLE II

AN OVERVIEW OF VARIOUS WIRELESS TECHNOLOGIES FOR THE POST-DISASTER EMS.

Technologies	**Advantages**	**Disadvantages**	**QoR**	**Deployment Cost**
LTE/LTE-A [10]	• Better indoor coverage • Lower interference	• Deployment in EMS is difficult	• Lower	• Expensive
Wi-Fi [11]	• Higher throughput • Works in ISM band	• Complexity in AP distribution	• Medium	• Relatively affordable
IoT [12]	• Distributed communication	• Very low throughput • Energy constraints	• Lower	• Affordable
D2D/MANET [13]	• Suitable for EMS • Easy to deploy	• Low scalability • Lower security	• High	• Affordable
UAV [3]	• Higher possibility of LOS communication	• Higher energy consumption for flight and communication • Limited capacity	• High	• Relatively affordable
Satellite [14]	• Higher coverage • Availability	• Higher delay • Lower throughput	• High	• Expensive

VI. USER AND GOVERNMENT RESPONSIBILITY

Post-disaster management is not only about the resilient communication technology but also the users' responsibility to effectively use such technologies. For instance, users should reserve access to the wireless network only for urgent communication needs. This helps to liberate the network components, scarce frequency bands and reduce the energy consumption. Moreover, the users should not make voice and data calls near the crowds because it increases the traffic congestion on a particular sector or beam of BS antenna array. This certainly helps to improve the quality of voice and other data applications by means of optimal call distributions.

The government also has an inevitable role to enable emergency communications during natural and man-made disasters. We cannot expect much from MNOs because they need to generate revenues to manage CAPEX and OPEX. The main responsibility of public safety belongs to the government for which they need to invest to achieve resilient communication systems. For instance, if dedicated spectrum for PPDR, especially in 700MHz bands, is causing inefficient spectrum usage, the government should proactively arrange spectrum sharing mechanism between the commercial services and PPDR agencies with minimum QoS guarantee to PPDR services.

Providing 700MHz to MNOs is in favor of immediate economic benefit but the dedicated band to PPDR in, for example, 700MHz will have a longer impact on socio-economic consequences [15]. It is important to note that the spectrum is not only valuable to the government but also society in equal terms.

VII. Conclusion

Since 5G is experiencing tremendous attention from the industry, government and academia, there must be sufficient provisions for post-disaster EMS. Moreover, the exact nature of post-disaster network scenario is unpredictable, it should, however, envision the concept of the autonomous and resilient systems. In this paper, we discussed post-disaster networks architecture, i.e., congested, partial and isolated networks along with the proposed solutions, such as D2D, IoT, MANET, UAVs etc. or any combination of them. The spectrum allocation for EMS applications has been studied within the 5G framework. The network solution and radio resource allocation for post-disaster EMS are expected to be useful for regulators, MNOs and emergency services. The concept will be further developed to design a unified frame of post-disaster EMS which will be tested on the heterogeneous 5G networks.

VIII. Acknowledgment

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