A COLLABORATIVE MODEL FOR POST FLOOD ACTIVITIES EXPLOITING AN ENHANCED EXPANDING NEIGHBORHOOD SEARCH ALGORITHM

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ABSTRAK

Di antara semua bencana alam, banjir dianggap sebagai bencana yang paling merosakkan tamadun yang menyebabkan kerosakan yang besar terhadap semua kehidupan dan harta benda. Setiap negara mempunyai pasukan penyelamat dan teknik untuk meminimumkan kehilangan dan penderitaan semasa banjir. Komunikasi dan kerjasama merupakan salah satu isu utama bagi operasi pencarian dan menyelamat semasa kejadian banjir. Keupayaan untuk mewujudkan komunikasi dan kerjasama dengan cepat di kalangan penyelamat adalah penting untuk menjalankan misi mencari dan menyelamat (SAR) yang tepat pada masanya dan berkesan. Sistem fizikal siber boleh digunakan untuk menyelesaikan tugas yang mencabar ini, kerana penyelidik menggunakannya dengan jayanya dalam domain yang berlainan. Tesis ini mencadangkan senibina rangkaian dalam bentuk model kolaboratif tanah udara siber (CP-AGCM). Tujuan model ini adalah untuk memperluaskan perkhidmatan kedekatan (ProSe) dan memperluaskan pertukaran maklumat tempatan-global yang bersepadu dalam aktiviti SAR selepas banjir. Dalam model ini juga, memanfaatkan spektrum TV White Space sebagai pautan backhaul rangkaian untuk memperoleh dan menyampaikan data kecemasan pasca banjir. Kaedah utama untuk membangunkan sistem yang dicadangkan dibina atas seni bina berlapis komunikasi tempatan, serantau dan kawasan tanpa wayar, dengan menggabungkan komponen rangkaian kolaboratif di antara lapisan. Fungsian yang diingini CP-AGCM dipamerkan melalui perumusan dan pembangunan strategi carian global yang efisien mengeksploitasikan pelbagai kolaborasi di kalangan ejen rangkaian. Hasil percubaan menunjukkan model kerjasama yang dicadangkan menawarkan platform komunikasi yang lebih berdaya tahan dalam persekitaran banjir yang teruk, dan seterusnya dapat meningkatkan jumlah mangsa yang diselamatkan dalam aktiviti SAR simulasi. Kajian perbandingan menunjukkan prestasi model yang dicadangkan bertambah 30% berbanding dengan model yang sedia ada. Prestasi rangkaian (sebagai contoh, Nisbah penghantaran paket yang mendekati 80-90%) juga menunjukkan keupayaan CP-AGCM untuk menyediakan ProSe dalam senario pasca banjir dan optimum algoritma carian yang efisien.

ABSTRACT

Among all natural disasters, flood is considered as the most civilization-destroying disaster which causes considerable damage to all life and property. Every country has its own rescue teams and techniques to minimize the loss and suffering during the flood. Communication and collaboration are one of the major issues for successful performing search and rescue operations during the flood occurrence. Such as, a crucial problem in post-flood recovery actions is the ability to rapidly establish communication and collaboration among rescuers to conduct timely and effective search and rescue (SAR) missions. The cyber-physical system can be incorporated for solving such a challenging task, as the researchers are exploiting it successfully in different domains. This thesis proposes a novel network architecture in the form of a cyber-physical enabled air-ground collaborative model (CP-AGCM). The aim of this model is to extend the proximity service (ProSe) and expand integrated global-local information exchange in the post-flood SAR activities. In this model, exploiting TV White Space spectrum as network backhaul links for acquiring and communicating post-flood emergency data. The primary method of developing the proposed system builds upon a layered architecture of wireless local, regional and wide-area communications, and incorporates collaborative network components among these layers. The desirable functionalities of CP-AGCM are showcased through formulation and development of an efficient global search strategy exploiting a wide range of collaboration among network agents. The experimental results show the proposed collaborative model offers a more resilient communication platform in harsh flood environments, which in turn can significantly improve the number of rescued victims in the simulated SAR activities. The comparative study demonstrates the performance of the proposed model improves 30% compared to the existing model. The network performance (e.g., packet delivery ratio nearing 80-90%) also demonstrates the capability of CP-AGCM to provide ProSe in the post-flood scenarios and optimality of efficient search algorithm.

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LIST OF SYMBOLS

$P_{Received}$	Received data packet
$P_{Generated}$	Generated data packet
A_i	Arrival time
S_i	Spending time
N_{RP}	Number of routing packets
N_{DP}	Number of delivered packets
ϑ	Number of victims
μ_p	Preparation time
μ_c	Searching time
μ_t	Reach time

LIST OF ABBREVIATIONS

ABS	Aerial Base Station
AMR	Adaptive Multiple Rate
APCO-25	Project 25
AGCM	Air-Ground Collaborative Model
CPS	Cyber Physical System
CP-AGCM	Cyber-Physical enabled AIR-Ground Collaborative Model
CRED	Centre for Research on the Epidemiology of Disasters
CA	Critical Area
DTN	Delay Tolerant Network
D2D	Device To Device
PDO	Packet Data Optimized
DMO	Direct Mode Operation
EM-DAT	Emergency Events Database
ENSA	Expanding Neighborhood Search Algorithm.
FANET	Flying Ad hoc Network
FRTN	Flying Real-Time Network
GPS	Global Positioning System
GSM	Global System for Mobile
GNSS	Global Navigation Satellite System
GPU	Global PDM Update.
GM	Global-Memory.
LTE	Long Term Evaluation
LM	Local Memory
LKP	Last Known Position
LOU	Local PDM Update
LADTR	Location-Aided Delay Tolerant Routing
LV	Land Vehicle
LCA	Land Covered Area
MANET	Mobile Ad hoc Network
MCPTT	Mission-Critical Push To Talk
NS-2	Network Simulator Two
NM	No Memory
NPU	No PDM Update
NAVSTAR	NAVigation Satellite Time and Ranging

PMR	Professional Mobile Radio
PTT	Push To Talk
PDM	Probability Distribution Map
PSA	Probabilistic Search Algorithm
PLS	Point Last Seen
QoS	Quality Of Service
RFID	Radio-Frequency Identification
RRH	Remote Radio Head
RBE	Recursive Bayesian Estimator
RSA	Random Search Algorithm
SAR	Search and Rescue
TVWS	Television White Space
TVBD	Television Band Device
TETRA	Terrestrial Trunk Radio
TETRAPOL	Terrestrial Trunk Radio Police
TEDS	TETRA Enhanced Data Service
TMO	Trunked Mode Operation
TC	Tropical Cyclone
UMTS	Universal Mobile Telecommunications System
UHF	Ultra High Frequency
UE	User Equipment
UAV	Unmanned Air Vehicle
VHF	Very High Frequency
V2V	Vehicle To Vehicle
V2I	Vehicle To Infrastructure
VSAT	Very Small Aperture Terminal
VP	Victim Point
WSN	Wireless Sensor Network
WLC	Wireless Local Communication
WRC	Wireless Regional Communication
WAN	Wide Area Network
WV	Water Vehicle
WCA	Water Covered Area
3D	Three Dimensional

CHAPTER 1

INTRODUCTION

1.1 Introduction

The report in the latest annual disaster statistical review (Below and Wallemacq, 2018) shows that natural hazards remain one of the major contributors to casualties in human population and destruction to community infrastructure. According to this report, flooding constitutes one of the top shares of natural disasters with recorded events of more than one hundred and claiming more than three thousand lives worldwide in 2017. The 12 floods killed 4731 and made 78 million people suffer. This statistics is only for 2016. Every year since 2006, the number of flood disasters has always been the biggest part of natural disasters and the frequency of flood disasters can be predicted from the annual disaster reports by (Guha-Sapir et al., 2015). Collateral damage figures further emphasize the unfavorable effects of flooding with approximately 55 million people being affected for the same year. Given wide-spread flooding occurrences and increasingly developed extreme weather cases (CRED and UNISDR), a flood management and mitigation approach is critical to reduce the severe impact of flooding. Central to this approach is the emergency rescue network that is necessary to provide timely and rapid responses to the occurring disaster.

Instantly after a natural disaster, the normal communication infrastructure is often severely affected including wired and wireless networks and is not able to guarantee for regular coverage and dependable communications services. Such temporarily-missing communications abilities are crucial to rescuers and victims as the responders require to effectively organize and communicate to reduce the loss of lives and property. The first 24 to 72 hours is a critical period for the immediate rescue operation and in this time a disaster tends to be very chaotic. Various communications among the flood rescuers that combine environmental sensing and intelligent processing as well as use a variety of data-centric services can give a better situational awareness and faster response time, and accelerate emergency management. Unfortunately, establishing such Proximity Service (ProSe) (Fodor et al., 2014) oriented emergency information exchange proves to be challenging for mission-critical post-flood SAR context due to the likely disruption and damage to the existing telecommunication operator's infrastructure and service.

The Cyber-Physical System (CPS) is a term defined as the emergence of a new generation of digital systems, less than a decade ago, which synthesizes computation, communication, and control technologies to achieve the performance, reliability and efficiency demands when managing the physical objectives in numerous application domains. It is represented information and communication technologies which one of the most significant advances in the development of computer science. As an emerging concept, CPS introduces many new paradigms in communication such as wireless sensor network in environment monitoring (Mois et al., 2016), Device-to-Device (D2D) communication in smart grid (Kim et al., 2018), wireless communication in the safety-critical system (Pop et al., 2017). As well as CPS is using to develop intelligent disaster-resilient networks in disaster scenarios (Nishiyama et al., 2017). With the advance of IoT wireless technologies, CPS can be more precisely in such a scenario for SAR activities. Consequently, rescue authorities and researchers are continuously looking for more advanced alternatives.

Several new techniques and technologies were proposed to improve the search and rescue (SAR) activities, which have permitted a faster response compared to the last few years. Although, most of these technologies are still not yet capable of responding as rapidly and accurately as demanded, mainly due to their non-collaborative characteristics. Communication and collaboration are one of the major issues for successful performing search and rescue operations during the flood occurrence. Due to this reason, the collaborative network has recently been focused on rapid SAR activities in the alpine environment (Rahman et al., 2018b). To fulfill this aim, the concept of CPS can be applied in flood-affected areas with a collaborative wireless network, referred as a cyber-physical enabled air-ground collaborative model (CP-AGCM) where TV white space is exploited as network backhaul links.

TV White Space (TVWS) refers to the unutilized broadcasting frequencies in the wireless spectrum. TV networks leave spaces between channels due to buffering purposes, and this gap in the wireless spectrum is similar to 4G spectrum and it can be used to provide widespread broadband communication. TVWS has excellent propagation characteristics since it is in the Ultra High Frequency (UHF) and Very High Frequency (VHF) spectrum bands. This results in long communication distance and better penetration through obstacles. The longer communication distance makes TVWS an attractive option for rural connectivity while the better penetration gives TVWS an edge over other technologies for machine-to-machine applications in dense areas. Due to this reason, TVWS provides a good option as the connectivity backbone for SAR operation.

In addition, some key parameters will be an important issue when focusing collaborative network on CP-AGCM. Such as, mobility is essential for deploying CP-AGCM effectively as almost all the rescue agents are non-static with diverse mobility characteristics. Like mobility, coverage is also an important factor since floods happen large-scale disaster therefore, the coverage area of the CP-AGCM should be more than the patrolled area. In CP-AGCM different actors exchange real-time videos and images. To allow such a real-time data exchange in the network, a sufficient data rate must be supported by the adopted wireless technology. In this perspective, the data rate is a crucial issue to develop CP-AGCM model. Energy becomes one of the significant issues in any hostile network scenario, there is a minimum supply of energy resources. In CP-AGCM most of the elements are battery-powered. Therefore, it is essential to reduce energy expenditure and select energy-efficient elements to extend the lifetime of the network.

In this thesis, the main concentrations are to collaborative SAR operation by considering some essential parameters. Therefore, we propose a CP-AGCM to improve the SAR activities where human rescuers, land vehicles, water vehicles, and drones are connected to each other for sharing the rescue information to develop a rapid and effective SAR model in the flood-affected area.

1.2 Problem Statement

Numerous models are presented for search and rescue operation in disaster situation, such as SHERPA (Rahman, 2014b), MANET system (Tundjungsari & Sabiq, 2017a), wireless multihop communication abstraction concept and the practical tree-based disaster recovery network scheme using the software-based access node approach (Minh et al., 2016), collaborative disaster management (Noran, 2014), ABSOLUTE project (Chandrasekharan et al., 2016), Collar-SAR (Rahman et al., 2018b), UAVs networks, where location-aided delay-tolerant routing (LADTR) protocol is used for UAV networks (Arafat & Moh, 2018), satellite-DTN emergency communication network (Asuquo et al., 2018). The main problem of the existing works is that there has no collaboration. The absence of collaboration makes more time to find the victims which may increase the number of fatality during rescue operation. Suitable technology is another issue, selecting suitable technology from the existing technologies make more faster and effective to search and rescue activities. Therefore, the following concerns are crucial when considering a communication framework for search and rescue operation in flood-affected area: (1) collaboration among the rescue agents (2) suitable technology with high data rate for rapid and easily create communication network and support rescue activities and (3) collaborative searching algorithm.

First, collaboration is a conversational working system among the collaborators in an organizational unit in order to achieve a specific task. In SAR operation, collaboration among the rescue agents is a paramount demand. Since floods are large-scale natural disasters that create very critical situations and human rescuers are not able to go to many areas. In this case, different domains e.g. land, water, and air are essential to SAR activities in such areas. A crucial problem in current systems for post-flood recovery actions is the lack of collaboration among rescuers to conduct a timely and effective search and rescue (SAR) mission given disrupted telecommunication infrastructure to support the service. The works (Rahman, 2014b; Rahman et al., 2018b) have done by the collaborative network however, they used two domains and applied it in alpine environments.

An effective Search and Rescue (SAR) system can assist the rescuers in finding the victims efficiently. The design of a SAR system is more challenging than others because of the harshness of the environment. In order to design an efficient SAR system for such a scenario, establishing seamless communication among the rescuers is one of the essential features. Due to a typical lack of this feature, the rescuer might visit an area that is already being searched by another rescuer, which reduces the efficiency of the SAR system.

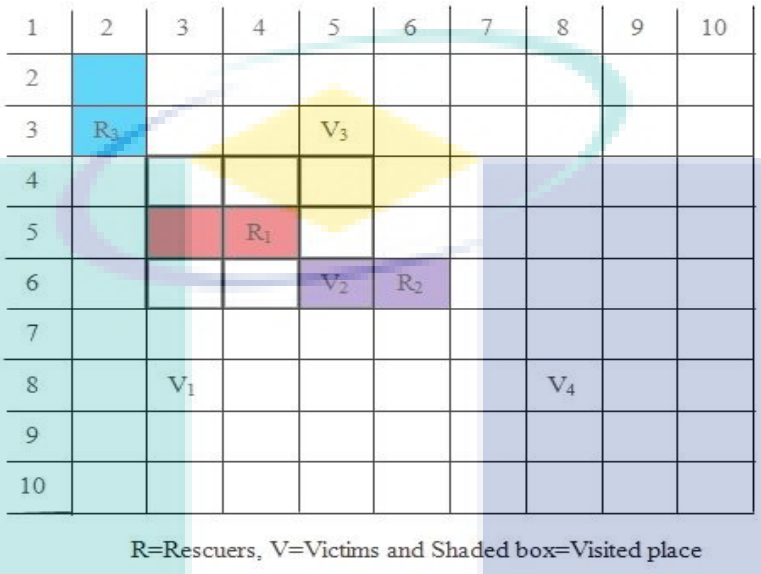


Figure 1.1 The impact of collaboration on flood rescuing system.

The system should be designed to depend on not only the single object observation but also multi-object observations. For clarity, we investigate this issue in Figure 1.1 where there are 3 rescuers and 4 victims located in a disaster area of size [10 × 10] grids. If the first rescuer, denoted as R1, visits to his next grid (6, 5) based on his own observation, it will not be an efficient move, since R2 already rescued the victims V2. Therefore, it is important to have collaboration among the rescuers in order to take an efficient move for the next grid. Moreover, the rescuers are not able to visit all the grids because of the harshness of the environment, i.e., some areas are covered by water or jungle and as a result, the rescuers cannot directly exchange information reliably. In order to access all the grids, three-dimensional collaborative efforts are required, i.e., incorporating air-, water- and ground-level collaboration. Both one and two-dimensional models have been proposed for a variety of applications (Adebanjo et al., 2017; Rahman, 2014a; Tuna et al., 2012), however, air-ground collaboration for such a disaster-rescue scenario has not been well addressed in the existing literature.

Second, after a flood disaster, a timely response is crucial and could be helped by restoring communication infrastructure in the first 24 hours. The reliable efficient communications are critical in any search and rescue (SAR) activities related to the flood situations (Altintas et al., 2014; Stirling, 2018). Various communications among the flood rescuers that combine environmental sensing and intelligent processing as well as use a variety of data-centric services can give a better situational awareness and faster response time, and accelerate emergency management. Most of the existing technological solutions (Chaves et al., 2014; Tan et al., 2018; Tundjungsari & Sabiq, 2017b) have been developed based on ad-hoc networking approaches, which lack extended communication range and have constrained the scope of rescuers' interaction. The deficiency of long-range communication capability is seen as a major hurdle for rich interaction and collaboration to timely accomplish SAR objectives. In addition. during a disaster situation, a large percentage of rescue agents gain and exchange instant videos, files, and images. To allow such an instant data alternation in the network, a sufficient data rate needs to be supported through the implemented wireless network. In this case, select a suitable technology and establish a resilient communication infrastructure to communicate among the collaborative rescue agents is a significant issue.

Third, there are many search algorithms that have been proposed to facilitate SAR activities in the last few decades and Probabilistic Search Algorithms (PSAs) (DeGroot, 2005) are the most popular algorithms, among the proposed SAR algorithms. However, most of these methods are non-collaborative and they integrate a Probability Distribution Map (PDM), that contains the probability values of the presence of a target(s) at various locations within the overall search area. In PSA, the starting cell of a SAR operation for a team could be determined based on several parameters including Point Last Seen (PLS) and Last Known Position (LKP) or could be determined randomly. If the target is not discovered in the current cell, the next visiting cell is selected based on the highest probability in the PDM within 1-level neighborhood. Generally, PSAs utilize local information to find the next visiting cell and hence, it is unable to exploit collaborative efforts of multiple teams. Therefore, in PSAs, multi-team revisits of a single cell are highly likely. In addition, PSAs and ENSAs cannot be directly applied in the flood scenarios and this scenario contains multiple victims points, which are distributed over a given area.

Motivated by these three considerations, we have considered a SAR model which can be served as a collaborative search algorithm to accelerate the searching operation.

1.3 Objectives

The aim of this thesis is to conduct a study of the CPS and develop a SAR model with TVWS network named CP-AGCM which can be suitable in flood-affected areas. In more details:

1) To propose a cyber-physical enabled air-ground collaborative model for post-flood SAR activities.

2) To design a communication network solution by exploiting the TVWS network.

3) To develop a collaborative search algorithm by considering the proposed communication network.

1.4 Research Scope

Cyber-physical system (CPS) is an emerging technology, that provides seamless connections among the cyber and physical worlds. (Jawhar et al., 2017)The cyber portion of CPS mainly concentrates on computing, for example, embedded computers. Nevertheless, CPS covering a progressively larger spatial field and unprecedented adjustment among the components into CPS and communication has become indispensable for the CPS. The Cyber attributes of CPS are now from its communication and computing subsystems. The physical portion of CPS relates to physical functions through that CPS interacts within its surroundings (Mao, 2013). CPS has to operate reliably, safely, and timely, at high confidence. The applications of the CPS have been acting important roles in different sectors as well as a communication network. We would furthermore narrow our concentration down to the wireless networks for CPS where TV white space has considered as network technology.

TVWS has recently been acknowledged as a promising new spectrum opportunity for wireless services, due to its low utilization (in many areas and at many times) and magnificent propagation performance. Particularly, TVWS offers unused or underutilized broadcast television spectrum (in the UHF/VHF frequency band) at a specific time and location. By allowing unlicensed wireless devices reutilize the TVWS in a license-exempt and opportunistic manner, that can effectively enhance the spectrum efficiency and alleviate spectrum scarcity in disaster situations. The TVWS components are better equipped in regards to data transmission capability, using higher-speed, large coverage, dependable links, for example, optical cable, microwave link or dedicated Ethernet. In the time of disaster, the benefit gained by operating air interfaces in the TVWS spectrum is twofold while compared with the GHz bands: larger coverage and better signal penetration provided by VHF/UHF wavelengths that increase signal propagation. Once the survivors are rescued from the disaster areas, high-definition photos of the rescued victim together with vital signs could be instantly transmitted to the medical specialists remotely situated in the control center where the cognitive BS is top-mounted. In addition, the rescuers can facilitate video stream to search remote areas and exchange real-time videos and photos with the control center. This would significantly enhance the efficiency of processes to protect the lives of victims.

CP-AGCM as an innovative construction of collaborative wireless network architecture with three domains utilizing air, water, and land networks to assist post-flood SAR operations. The system adopts a layered network architecture comprising wireless local communication (WLC), wireless regional communication (WRC) and wide area network (WAN). A key element of this architecture is the cognitive radio-oriented TVWS channels as network backhaul links. This layered network construction, fully collaborative network components can be incorporated along the aforementioned layers to handle the uncertainty of a flood disaster and its impacts.

In this research, CPS is used with TV white space technology for seamless communication. This communication system is used with CP-AGCM in flood disasters for SAR activities which is the more challenging but also a higher-rewarding task.

1.5 Research Methodology

In this thesis, the main research procedure involves four stages which are mentioned in the following: (1) the first stage is describing the problem statements with conducting a literature review in this thesis. (2) The second stage concentrates design issue of CP-AGCM and exploiting TV white space network as backhaul links while CP-

AGCM introducing with SAR operation. (3) The third stage defines the proposed CP-AGCM strategy and validates the expected requirements. (4) Lastly, the fourth stage narrates the result and discussion with ascertaining picturesque explanation and afterward the summary is presented with future recommendations.

1.5.1 Phase 1: Literature Review and Mentioned Problem Statements

The survey of the extensive literature on the existing different emergency networks in a SAR operation reveals few directions for design an appropriate network during emergency disaster situations. These parts define the various challenging issues upon designing CP-AGCM. The existing network technologies and their features, applications, merits, and demerits are presented in this part. Network coverage, mobility, data rate, latency, energy expenditure enabling collaboration among all the components are the challenging issues in such a hostile environment that are discussed here. Finally, a tabular diagram is presented by related works.

1.5.2 Phase 2: Architecture and Implementation

The architecture and implementation stage should be well designed for establishing robust and reliable communication. The system model issue includes better coverage, high mobility, high data rate, low latency, low energy expenditure, and security. In this phase network materials and network architecture also presented.

1.5.3 Phase 3: Proposed and Validate

The proposed model CP-AGCM is tested with network simulation. The collaborative system is validated by MATLAB, the ENSA-MV is validated by C++ and the networking of CP-AGCM is validated by NS-2 simulator. The detail simulation results have been discussed in chapter 4.

1.5.4 Phase 4: Result and summary

The experimental answers are analyzed and an in-depth conversation has been made as of this stage. As well as in the consequent stages, the achievement of this proposed solution is evaluated. Finally, an overview is offered for future tips.

1.6 Outlines of the Thesis

This thesis was arranged in a manner that clarifies the subject from all aspects; it provides details on the facts, observations, arguments, and procedures to achieve the objectives. The thesis contains five chapters. Thesis Organization is hereby presented:

Chapter 1: Introduction: the thesis introduction presents the following in the specified order: the importance of designing a collaborative model, the problem statement, the main objectives, the scope, and the thesis organization.

Chapter 2: Literature Review: It includes a detailed explanation of the major concepts of the thesis that were highlighted in Chapter 1; reviews relevant literature in order to establish the background for this research. Specifically, a detailed review of the literature on network algorithms was done and discussed studies related to the objectives of the present study.

Chapter 3: Methodology: This chapter presents a detailed methodology used in this study. It specifically discusses the hypothesis, the proposed collaborative model with a Backoff component and the experimental parameters used in the study. The chapter ends with the presentation of the methodology flowchart.

Chapter 4: Experiments and Results: This chapter discusses the experimental set-up of the different experiments performed in this study, examining the results and validating the experimental outcomes with the results from other studies.

Chapter 5: This chapter presents the conclusions and recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

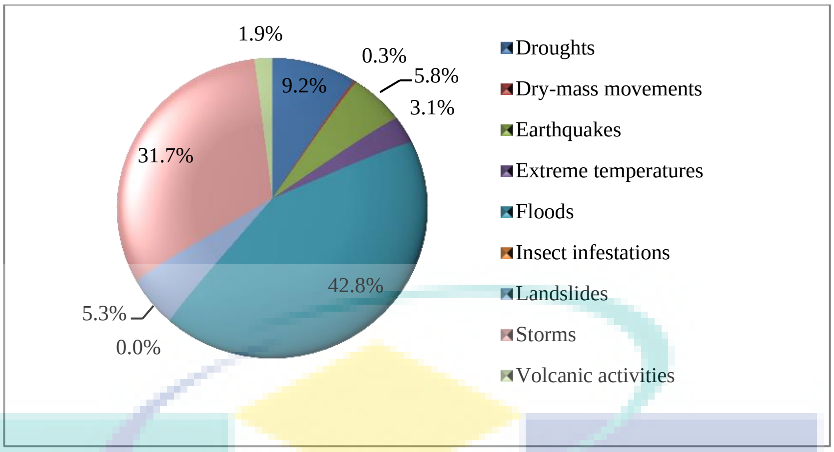
Numerous large-scale natural disasters such as floods, earthquakes, tsunamis, cyclones are very common around the world every year. Different search and rescue (SAR) organizations protect the well-being of the public in case of such natural disasters and are tasked with preparing, planning, and responding to emergencies. Disaster management is a critical and urgent research issue. Effective emergency natural disaster management depends on the efficient mission-critical voice and data communication among the rescue agents as well as rescuers and victims. In this case, wireless communications are particularly important in field operations to support the mobility of rescuers. Recent disasters have emphasized the need to enhance interoperability, capacity and broadband connectivity of the wireless networks used by SAR organizations. The communication technologies such as Ad Hoc, LTE, TV white space, satellite, TETRA, APCO-25 networks are largely used by search and rescue organizations. However, the capabilities of these technologies are different. Communication capabilities need to be provided in very challenging environments where critical infrastructures (e.g., energy, communications) are often degraded or destroyed by the impact of the disaster event. Moreover, natural disasters are generally unplanned events, causing panic circumstances in the civil population and affecting existing resources (e.g., infrastructure, transportation), which makes the task of rescuers even more complicated. Therefore, selecting a suitable technology is a crucial issue in disaster situations.

In the remainder of this chapter, an extensive literature review has been made on different existing wireless networks that will include features, limitations, and applications associated with emerging technologies. As well as some challenging issues are discussed for developing a resilient network in disaster areas.

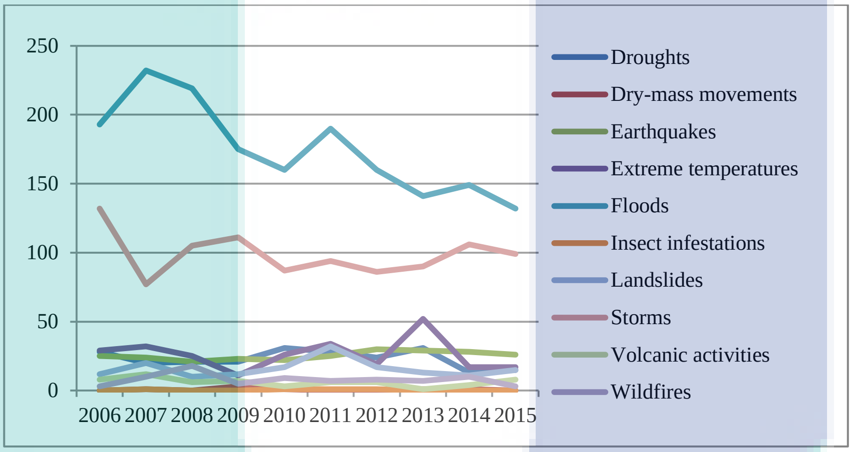
2.1.1 Impact of Floods

Floods are the serious socio-natural disaster affecting social and economic aspects of life. The magnitude of undesirable impacts relies on the vulnerability of the activities and population and the frequency, strength and extent of flooding. Immediate effects of flooding include loss of human life, destruction to property, damage of crops, loss of animals, non-functioning of infrastructure facilities and degeneration of health situation due to waterborne diseases. Flash floods, with little or no warning time, cause more deaths than slow-rising riverine floods. According to the UN report "The Human Cost of Weather-Related Disasters (1995-2015)" was published in January 2016, where 15700 people have died as a cause of floods in the last two decades. Following this report, from 1995 to 2015 2.3 billion people are floods affected, which calculates for 56% of all those affected by weather-related disasters, significantly more than any other kind of weather-related disaster. The report also says, that from 1995 to 2015 flood disasters were 3062, which calculated for 47% of all weather-related disasters and 43% of all natural-related disasters that also includes geophysical hazards such as storms and earthquakes (CRED, 2015).

A similar another report titled "world disaster report 2016" has published by the world's largest volunteer-based humanitarian network "The International Federation of Red Cross and Red Crescent Societies (IFRC)".According to this report, there were 154 flood disasters only in 2015 and 114 storms and 33 droughts in the second and third positions. From the pie chart, we see that a greater percentage of the disaster was happened by the flood which is 42.8%. Storm and drought were periodically 31.7% and 9.2%. Other disasters take a smaller amount as shown in Figure 2.1 (a) and 2.1 (b).



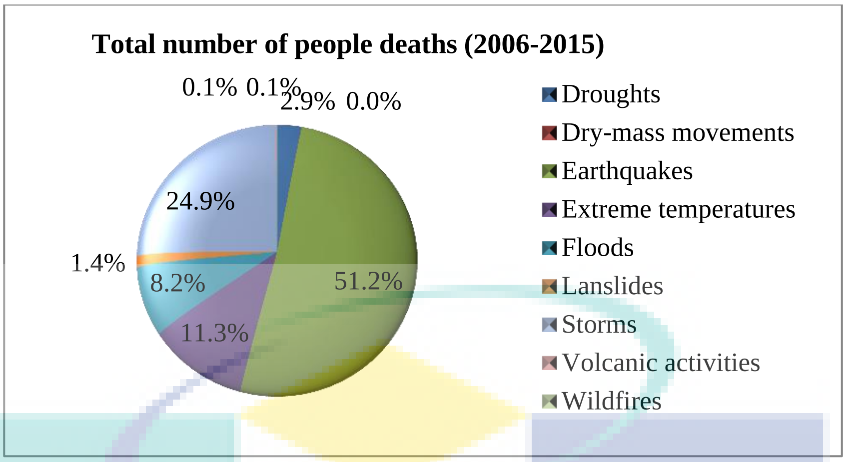
(a)



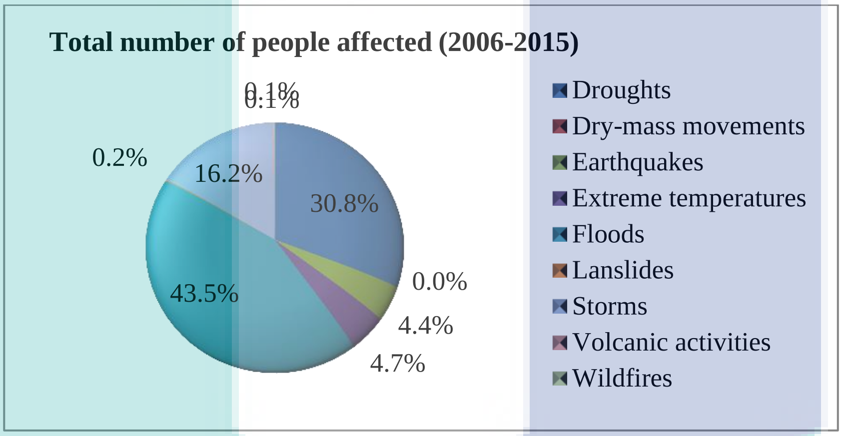
(b)

Figure 2.1 (a) Percentage of disasters in 2015 and (b) Number of disasters from 2006 to 2015. Source: EM-AT, CRED, University of Louvain, Belgium.

Similarly, from 2006 to 2015 the total flood disasters were 1719. The second and third disaster storm and drought were 970 and 235. The report says that 57027 people have died between 2006 and 1015 by flood disaster which is 8.2% as illustrated in Figure 2.2 (a). It also says that in this decade the total number of people affected by the cause of the floods was 83095. Stand for 43.5% of people affected, which is greater than the other percentage of affected people from other disasters as shown in Figure 2.2 (b).



(a)



(b)

Figure 2.2 (a) Percentage of peoples' deaths (2006-2015) and (b) Percentage of people affected (2006-2015). Source: EM-DAT, CRED, University of Louvain, Belgium.

2.1.2 Activities of Floods

Exposing to the calamity of several types and severity created a complex environmental issue. Rapid onset disasters that need quick response time such as floods require fast and coordinated actions of several actors. (Alamdar et al., 2017). For fast and coordinated action, there have three phases of flood activities which are pre-flood, in-flood, and post-flood.

Pre-flood Activities: Pre-flooding activities are carried out in order to prepare for flood events. An appropriate preparedness for pre-flood deeds can improve public safety, alleviate social damages and minimize economic losses associated with floods.

Preparedness is defined as establishing effective response to the adverse impact of hazards, including assigning timely and effective early warnings and the temporary evacuation of people and property from threatened locations (Fakhruddin et al., 2015; Koriche & Rientjes, 2016). It requires time and resources to develop this ability.

In-flood Activities: During floods, establish search and rescue action to reduce the impact of the flood disaster in order to prevent financial loss and avoid further suffering of the flood victims. This phase includes activities are bringing suffering people from risk zone to safe zone, supplying foods, water, medicine, and shelter, monitoring the flood situation, etc. The aims of search and rescue operation to manage the overall likelihood and negative impacts of flooding on people, the economy and the environment.

Post-flood Activities: Flood relief operations for affected people are the main task after floods. Establishing effective planning and enlisting of relief operation can benefit greatly in mitigating suffering. Flood relief operations can take many forms including establishing emergency facilities, providing temporary accommodation and financial support, providing health and medical care, distributing aid, transferring injuries, an effort to restore public facilities and houses, etc. of the affected areas to its original state and adjustment of this activities over organisations (Y.-J. Zheng et al., 2015).

2.2 Related Work on Communication infrastructure for Disaster Management

Various works have done for disaster management based on different communication infrastructures such as Ad hoc network, LTE, satellite communication, TV white space, UAV network and more. Most of these works are focused on natural disasters where include floods, flash floods, earthquakes, and cyclones. Therefore, in this section we have reviewed natural disaster based works and the technologies that are used in these works. In order to give a more complete view of disaster management, these technologies can be divided into few subsections.

2.2.1 Communication Services

Generally, when a disaster occurs, network infrastructures are damaged and communication channels are unavailable or unreliable. In this case, to minimize the loss of life and wealth communication network is imperative. Therefore, the first step is needed to establish a communication network. Then, the mentioned different services and abilities are required from this established communication system that will speed up the rescue operation by rescue actors. The taxonomies of this mentioned communication services are specificed in various articles such as (Cmara & Nikaein, 2015; Fragkiadakis et al., 2011).

Voice: In disaster operations, voice is the elementary form of communication by rescuers, although data-based communication is becoming important progressively. In this service, require real-time full-duplex communication that can be of extreme utility in the instant consequence of the disaster. Because of this, voice communication must guarantee a specific level of quality compared to commercial networks to make ensure the requests and responses between rescuers are clearly understood and they are not ambiguous, even in emergency situations where background noise could be present (e.g., crowds, shoutings, explosions) (Rekha et al., 2016).

Group Communication: This is another significant concept of rescue teams where voice could be established as group communication. Hence, a pre-defined user group can engage in such communication. Such as all the rescuers in a team within a particular hierarchical level.

Video: In complex disaster scenarios, rescuers often need to search by camera-equipped drone. This can necessitate the real-time video transmission to an operation center. Also, sometimes rescue agents need to share urgent information where real-time video streaming can be used. Each of them specific Quality of Service (QoS) is required (Miaoudakis et al., 2014).

Data connectivity: It defines the interactive data communication (i.e., messaging is not included) between one or more parties when there is the query created and a response provided. It includes various types of data communication such as a query to distant data servers and others.

Push-To-Talk: The feature of Push-To-Talk (PTT) enables half-duplex communication service between two rescuers in emergency situations. It is also known as "press to transmit" that provides instant communication by simply pressing a momentary button to switch a device from voice transmission mode to voice reception mode. With this service, a user can talk that one or even more other users can hear. It is very easy to activate as well as durability and safety (Mate et al., 2013).

Messaging: This is a non-interactive data communication and exchange of messages among rescue agents or between rescuers and victims. The exchange of messages can instantly text, SMS or email. The message can distribute as multicast or broadcast.

Location service: It refers to determine the location of victims or vehicles in the disaster terrain. Victim's locations could assist first responders to provide rapid rescue and medical support. Location information can be supplied by GNSS. Presently, some global GNSS are available, such as the USA NAVigation Satellite Time and Ranging (NAVSTAR) Global Positioning System (GPS), the EU Galileo, the Chinese navigation system (BeiDou) and the GLObal NAvigation Satellite System (GLONASS) in Russian. The GNSS accuracy depends on the number of satellites in Line-of-Sight (LOS) of the receiver. The cellular networks, for example, Universal Mobile Telecommunications System (UMTS)/Global System for Mobile (GSM)/ Long Term Evolution (LTE), could also be used to search the victim's location (Usman et al., 2018).

Data rate: In the case of SAR operation that builds on network connectivity, an important necessity in this network connectivity is the amount of data rate available to assist this operation. For example, in the remote flooded area, video streaming is unusable by rescue agents, if this streaming is not supported by the network with sufficient bandwidth, otherwise, the video quality and the resolution will not be adequate for the functional needs of the rescue agents.

2.2.2 Infrastructure-less Network for SAR Activities

Ad hoc networks are being seen as the fitting candidate for search and rescue activities, due to their distributive multi-hop, self-organized and features. These networks are wireless overlay networks that make data transmission possible without the wire. It acts independently without any kind of prior existing infrastructures like base stations. Nodes in ad hoc networks transmit data in a multi-hop system, that means, source nodes send data towards target nodes by forwarding nodes (Tan et al., 2018). In the case of damaged or overwhelmed communication networks, as ad hoc network support could be greatly useful. Numerous works have been done for search and rescue using ad hoc technology. For example, Ray and Turuk (Ray & Turuk, 2017) used a wireless ad hoc network for post-disaster communication to decrease the losses, as well as save the breaths of human beings and animals, George et al. (George et al., 2010) proposed an architecture named DistressNet, based on wireless sensor and ad hoc networks for supports disaster response in wide area and Saha et al. (Saha et al., 2015) presented a hybrid 4 layer ad hoc network infrastructure to develop communication into the consequence of natural disaster. See more example in (Quispe & Galan, 2014; Reina et al., 2014; Reina et al., 2013). In this section, we have discussed the main features of various ad hoc network paradigms and their applications such as MANETs, VANETs, FANETs, AANETs, and DTNs.

2.2.2.1 TV White Space

Television white space (TVWS) is defined as the unused spectrum in the broadcast of TV bands which can potentially be utilized for substitute wireless communications (W. Zhang et al., 2018). Presently, the growth of mobile smartphones increasing the demand for the radio spectrum. This quickly accommodates the demand for wireless services. The effort of spectrum regulatory is currently continuous in numerous countries to permit secondary entry to the spectrum of the TV channels. Temporarily unused through licensed consumers are known as incumbents. This type of non-adjacent empty channels is referred to as TVWS (Cacciapuoti & Caleffi, 2015). The spectrum regulators are mentioned condition to the secondary users in TVWS secondary communications to avoid harmful interference for incumbents. To this reason, spectrum regulatory have recommended a database-aided TVWS network infrastructure for successfully reuse the spectrum of TVWS without damaging the licensed device interests. In this infrastructure, unlicensed white space devices obtain the presented TV channel information by querying an authorized geolocation database located in the cloud. This process requires storing and periodic modification of relevant information capturing network architectures of TV licensees and their channel occupancy (Luo et al., 2015).

Recently TVWS has been acknowledged as an encouraging movement to acquire new access to frequency spectrum for wireless communication services. Benefitting from its typical underutilization in a wide range of places, TVWS is unique due to its excellent propagation features and friendly path loss characteristics (FCC, 2010). The superior propagation attributes of TV spectrum permits a high transmission range with low energy requirements which makes him at a compatible candidate for large-scale disaster scenarios such as floods, earthquake, etc. TVWS can easily cover an area of about ten kilometers in dimension. While a conventional Wi-Fi router has a comparatively limited range, about 100 meters with perfect conditions, as well as could be blocked by walls, building or other environmental obstacles. This advanced technology is known as “Super Wi-Fi” considering its better range and capability to penetrate barriers such as buildings, trees rough terrain. Non-line-of-sight is the other important feature of TVWS. Microwave link needs line-of-sight among the points to be connected. In forested or rugged landscapes, the long tower essentially gives such line-of-fight connection which makes microwave a costly and unfeasible solution. Conversely, TVWS provides a good option to microwave through using the low-frequency UHF (Ultra high frequency) signals which can penetrate barriers and cover unequal ground without needing extra infrastructure. For example, in (Hasegawa et al., 2013) discussed the WRAN system for disaster-resilient communications, and further designed and implemented a prototype of wireless system using TV white space based on IEEE 802.22 standard. Reference (Villardi et al., 2012) proposed a portable cognitive emergency wireless network by operating TV white space. It is anticipated that in the time of emergency, the advantages offered by air interfaces utilizing TVWS spectrum (VHF/UHF bands) as compared to those utilizing the GHz bands include wider coverage and higher signal penetration.

TVWS for Search and Rescue Missions: The use of TVWS technology in SAR missions offers numerous advantages more than PMR technologies. TVWS technology is able to run broadband services which demand videos, photos, and files. Adopting TVWS for SAR networks will uncover the door for newer applications, for example, live video conferencing, video streaming, tracking, field sensing, and many more services that offer more advantageous than the current PMR for SAR networks.

TVWS enjoys the considerably greater range, enabling access points to be set up in areas up to a couple of kilometers far from the VSATs location – generally the demand center. This makes it in an easier way to manage traffic within the vicinity associated with the demand center. Additionally, the TVWS antenna may be situated indoors. The capability to locate TVWS antennas indoors in the aftermath of a disaster event is therefore particularly advantageous. TVWS network is easy to Install for first-response rescue teams. Aligning radio antennas could be easily established and no need to exact alignment and even can operate in obstructions and above water. During disasters in Philippines the components used were weatherproof, and anywhere could be installed, with a general antenna (Microsoft, 2011).

One advantage of utilizing white spaces systems is that a single base station could work with numerous endpoints and it is inevitably a multipoint technology, no require for line-of-site connectivity or to set endpoints properly. Which means it is able to work in high winds.

Spectrum Allocation for TVWS-based SAR Missions: The regulatory bodies of different countries are accountable for allocating accessible spectrum for professional and governmental processes incorporating public safety systems, for example, OFCOM in U.K., ECC in U.S.A., and ISED in Canada. Many countries made the decision to specify for emergency broadband usage. The Canad and U.S.A. selected 20 MHz in 700 MHz spectrum for public safety broadband usage to deploy a domestic interoperable PS network. Among them, 10 MHz is allotted for uplink signals and the remaining 10 MHz for downlink transmissions. 20 MHz in the 700 also allocated in South Korea for their public safety Network. Nevertheless, the countries in North American rules allow commercial spectrum to share the public safety spectrum on the emergency situation that the public safety traffic remains a priority. It is even significant to understand that the 700 MHz band has magnificent characteristics that enable wide coverage with fewer base stations that decrease the cost of implementation. It also guarantees a better efficiency for establishing communications owing to its excellent penetration characteristics.

TVWS System Architecture: Two methods are illustrated in for TV band device (TVBD) to obtain the channel availability information (CIA), namely, spectrum sensing and geo-location database access. In the first method, TVBD acquires the CIA independently by using local spectrum sensing. Numerous spectrum-sensing technologies have been developed, for example, compressed sensing, pattern recognition based sensing, waveform-based sensing and energy detection. In the second method, a TVBD first determines its location and sends a CIA request to its closest TVWS database to obtain a couple of operating parameters, for instance, available channels, as well as allowable transmit power, pertinent to its location. For achieving this, the geo-location database requires to house as well as periodically modify information associated with network infrastructures of TV licensees and their channel occupations. After receiving the request the geo-location database replies to the TVBD with the CIA near TVBDs location. Since the database access method is considered to be more precise, that is regulated as a mandatory technology for all TVBDs through the FCC, when spectrum sensing is regulated as an optional technology. To effectively reuse the TVWS spectrum without harming the interests of licensed devices, spectrum regulatory bodies have advocated a database-assisted TVWS mechanism. Hence, the geo-location database is the central network entity in such a network.

Figure 2.4 demonstrates a database-assisted TVWS network architecture. Hence, the system can be divided into four steps. In step one, the geo-location database updates white space information. In step two, to access TVWS, TVDBs report their locations to a geo-location database. In step three, the database computes and returns the available TV channels information that TVBDs can utilize in a particular time period. And in step four, the TVBDs provide end-users access using the obtained spectrum.

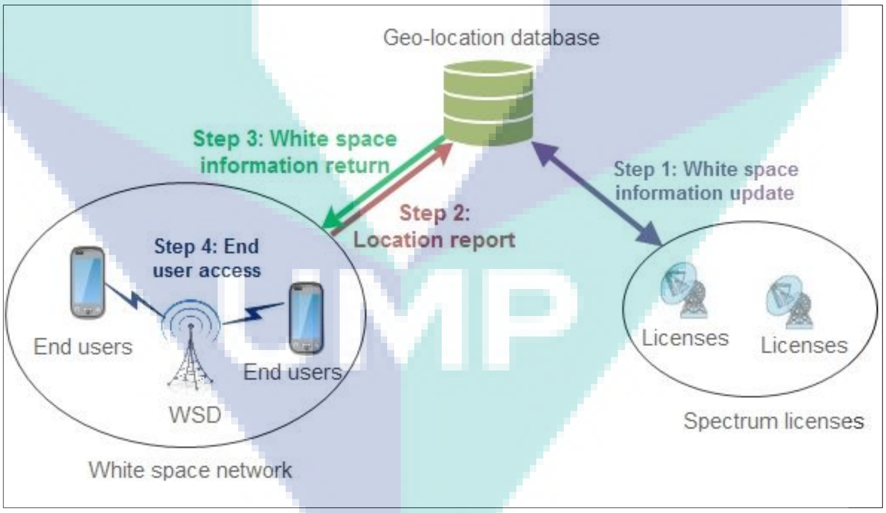


Figure 2.3 TVWS network architecture.

Thus illustrated in Figure 2.4, each TVBD is works as an infrastructure-based device (e.g; a base station) operated by a secondary operator, and also provides cellular-based wireless facilities to its subscribed end users by utilizing TV channels.

2.2.2.2 Long Term Evaluation

Long Term Evaluation (LTE) is a high-speed wireless communication technology for mobile devices that has been specified by the Third Generation Partnership Project (3GPP). As an emerging mobile communication technology for the next generation broadband mobile wireless networks, it is progressively adopted by all major operators all over the world. The packet-based system is applied to the LTE system, containing fewer network elements that improve the capacity and coverage and also provides higher performance with regards to high data rates, low latency, convenient bandwidth operation and smooth integration with different existing wireless communication systems. Actually, LTE is a first-generation 4G technology. The major advancement of LTE is LTE-Advanced or LTE-A. It supports much higher data usage, lower latencies and better spectral efficiency (Cao et al., 2014).

LTE has chosen as the base technology for future emergency PS networks. The initial step was to complete the gap among PS mission-critical demands and LTE functions. Great efforts have been made by the 3GPP in standardizing LTE PS-driven services. Recently, the 3GPP is upgraded the current LTE-based architecture to enable broadband public safety (PS) communications. In order to upgrade the current services, the 3GPP TS 22.179 Rel-13 has launched mission-critical push-to-talk (MCPTT) services. In this release, MCPTT allows the direct mode communication and adds the device discovery function to find surrounding users by operating either network support mode or direct-mode except for network support. In Release-13, further improvements to Proximity-based Services (ProSe) for assisting the PS that fulfills the requirements of MCPTT. Specifically, Release-13 focused on enhancements to Direct Discovery such as request/response discovery and discovery restricted and improvements to Direct Communication, for example, one-to-one communication. The ProSe direct communication allows creating communication links amongst the discovered users which lie in the surroundings while the previous discovers the neighbor users through broadcasting a beacon (Kaleem et al., 2018).

LTE-driven isolated E-UTRAN operation for PS another important service that enhanced the strength of PS networks. This approach is introduced to maintain communications, even while the backhaul connection is lost to the core network. It consists of isolated E-UTRAN, backhaul links, local EPC, and an application server. The isolated E-UTRAN has a nomadic eNB (NeNB) that has the ability to move and supply communication links during the emergency disaster situations (Oueis et al., 2017). LTE technology can be supported most of the services are mentioned in II.A.

Figure 2.6 depicts the LTE public safety services, where 2.6(a) depicts the group communication system. In this case, the group communication system enabler (GCSE) implementation needs a group call enabler for LTE network, dispatcher, group call application server, group members, user equipment (UE) relays, and enhanced NodeBs (eNBs).

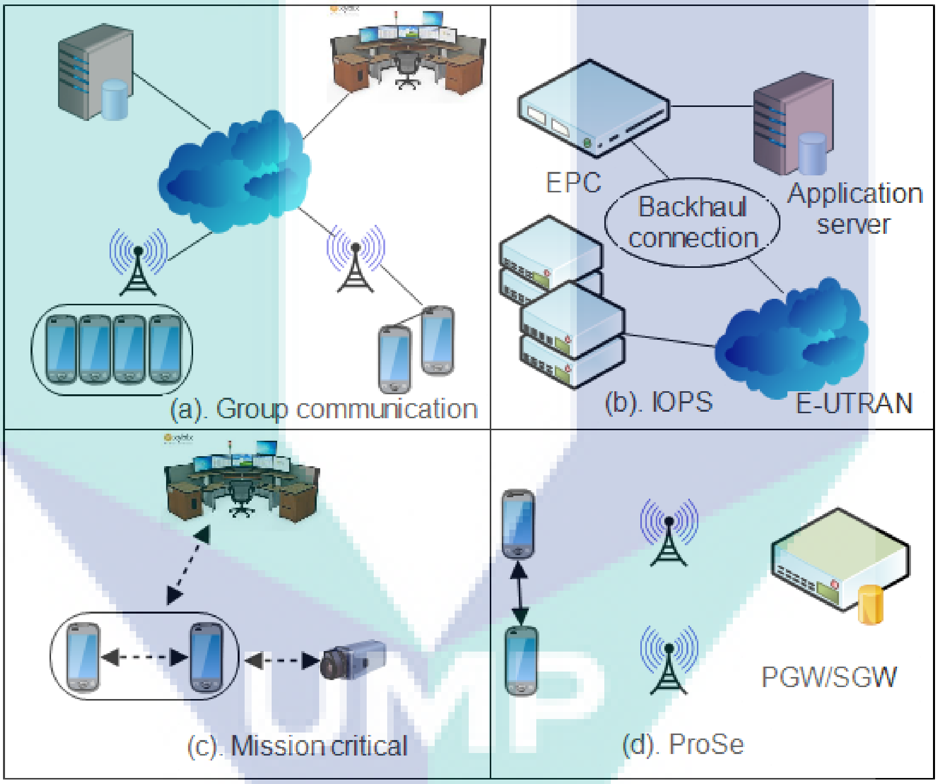


Figure 2.4 Emergency PS LTE services.

The strength of PS networks could be improved by enabling LTE-founded isolated E-UTRAN operation for PS (IOPS). This idea is introduced to continue communications even while the backhaul connection to the main network is lost that depicts in Figure 2.6(b). Figure 2.6(c) demonstrates the mission-critical network service that provides urgent communication services during a disaster when a base station in lieu of damage. D2D communication connections will be set up to provide alternate communication links. Figure 2(d) shows the proximity service in PS-LTE to allow direct communications amongst the neighboring users.

Applications: In recent years, numerous approaches have emerged to address the emergency network in disaster areas. Such as, Kaleem et al. (Kaleem et al., 2018) proposed a disaster-resilient architecture for PS based on LTE that provides the emergency communication networks in disaster-affected areas. It combines the cloudlets and software-defined networks, which help to achieve the QoS and latency requirements of the network users by both centralized and distributed processing.

The authors in (Gomez et al., 2016) designed a technical solution with higher capacity and large coverage abilities for the broadband emergency disaster communications where LTE technology has adopted predominantly. Hence, this system is composed of terrestrial and aerial segments. In disaster scenarios, embedded terrestrial mobile land station and aerial platform are made a flexible base station where satellite segments provide backhauling functionalities. This technique remarkably enhances disaster recovery by existing LTE spectrum by exploiting energy-efficient cognitive mechanisms. Queis et al. (Oueis et al., 2017) discussed the general concept of Isolated E-UTRAN Operation for Public Safety (IOPS) in the consequence of a disaster. It includes the network installation and configuration requirements, user equipment (UE) configuration, mobility scenarios, and security considerations in an IOPS network. Then, they discussed the future perspective for the evolve IOPS and find some research opportunities.

The two main radio technologies such as device-to-device (D2D) communications and user equipment (UE) started multicast communications are investigated by Zhang et al. (G. Zhang et al., 2017). They have considered UE as a multicast transmitter instead of BS after damaging network infrastructure in post-disaster areas. Then, they proposed an effective opportunistic multicast scheduling strategy at MAC layer that minimizes the delay of multicast and improves the QoS of emergency group communications.

2.2.2.3 Satellite Communication

In telecommunications, satellite communication uses artificial satellites to provide communication links between numerous points on the globe. In the global telecommunications system, the contribution of satellite communications is significant. Approximately 2,000 artificial satellites orbiting Earth operate analog and digital signals carrying voice, video, and data to and from one or many locations globally. Satellite networks could transmit in different frequency bands, for example, C-Band, Ku Band and they usually provide comprehensive coverage. Mainly satellite communication has two components. One is a ground segment, that comprises of fixed or even mobile transmission, reception, and supplementary equipment, and another one is space segment, which primarily is satellite itself. The fixed terminal can be Very Small Aperture Terminal (VSAT) that normally provides a high data rate (according to the demand of 1.5 MB or more) than mobile terminals. The Mobile satellite terminals are based on portable terrestrial terminals. It can be set up on trucks, automobiles, airplanes or even ships. A standard satellite link transmits or uplinks a signal to a satellite from a surface station. The satellite receives and amplifies the signal and retransmits it return to the surface. Then the signal is received as well as reamplified through earth stations and terminals.

The mobile terrestrial terminal could be a significant asset to SAR domain by supplying almost full coverage using the additional avail of mobility. Because satellite networks do not depend on terrestrial permanent infrastructure and usually they have a quite large coverage. This network is especially adept to assist SAR organizations, in particular scenarios such as natural disasters. In this scenario, they could be used satellite networks to provide a direct connection between the rescue agents in the disaster areas and the remote control centers.

Applications: The article (Pecorella et al., 2015) presents a short review of solutions for emergency communication services offered by satellite network systems. It includes the current activity of public search and standardization in the fields. Hence, the authors described integrated network architecture that can be incorporated heterogeneous satellites, MAVs, UAVs, and an NCC. Indicated here that Satellite very small aperture terminals (VSATs) are the favorite choice, since they provide broadband abilities with the ability to backhaul terrestrial traffic which comes from cellular, wireless, professional mobile radio (PMR), and voice over IP (VoIP) networks. In (Yang et al., 2016) the application is proposed reliable hybrid wireless communication for disaster management that consists of satellite and terrestrial MANET network.

Hence, the authors present a novel routing mechanism with reactive routing protocols that fulfill the QoS requirements such as higher packet delivery ratio, higher throughput, and lower delay. In this mechanism, the multipath routing principle in AOMDV is used in the process of gateway selection. Each node also monitors the status of all other available APs (gateways) in order to three metrics, i.e.; residual path bandwidth, latency, and reliability, instead of being assigned to a particular AP.

2.2.2.4 Mobility Aware Infrastructure-less Network

A MANET is generally a form of ad hoc network Mobility Aware Infrastructure-less Network which can alter locations and continuously configure itself by mobile nodes which interconnect through wireless links and also autonomous infrastructure-free wireless networks. The topology of MANETs changes because of the mobility of the users as well as information can forward from the source to a destination by hop-to-hop transmission. The dynamic nature and mobility of MANETs demand for new setup of networking techniques to be developed in order to provide efficient and trustworthy communication during emergency search and rescue, disaster relief and small tactical unit operations where the current telecommunication infrastructures may be damaged or are unavailable. In a natural disaster scenario, quick and accurate response and action are indispensable for an effective rescue. Spreading group data and important information are time-bound. In addition to that, the dynamic, as well as the self-configuring feature of MANET, is attractive and appropriate for emergency disaster recovery networks. Below are different attributes of MANETs that make it proficient and dependable network for flood disaster communication.

Multihop communication: Remark that data exchange in MANETs between any two geographically-separated terminals typically involves numerous intermediate nodes. To share information, it forwards information packets from a point to another point in the network until they reach the intended destination. This fundamental function of MANETs provides a trustworthy network for flood disaster scenarios.

Infrastructure less network: MANET work without preexisting fixed infrastructures. It is the most significant characteristic which gave birth to this kind of network. In many environments, the presence of infrastructures is not insured, specifically in the environments where the implementation of fixed infrastructures is challenging or impossible. The networks are constructed upon mutual understanding among peer-to-peer autonomous may dynamically change over time.

Network scalability: Large MANETs can be developed using a few thousands of nodes, considering its dynamic and infrastructure-less nature such as tactical network and sensor network. Scalability is vital to the effectual implementation of such networks. The develop a large network comprising of nodes among restricted resource are not easy and still present many challenges issues like addressing, location management, routing, configuration management, security, interoperability, etc.

Dynamic network topology: The nature of MANETs nodes are arbitrary, thus the network topology can change quickly and unpredictably. The networks itself will dynamically adjust according to traffic designs, propagation conditions, and mobility pattern. The mobile nodes randomly move their position from their own network in any direction and any speed about whenever there is a need. Such nodes could arbitrarily join and leave the network

Short-range connectivity: Reliable transmission in MANETs is highly governed by the utilized radio frequency (RF) connection. Each node needs to be inside the frequency range. This design will equip multi-hop routing systems to connect remote nodes acting as routers and subsequently forward the packets for spreading among the mobile nodes through the intermediary nodes.

2.2.2.5 Vehicle Aware Infrastructure-less Network

Vehicle aware infrastructure-less networks are promising mobile ad-hoc network usually known as VANETs. These networks are rapidly deployable wireless communication technology and able to simplify data exchange amongst the vehicles and supplies diverse data services (Qiu et al., 2018). In disaster scenarios with regards to the application, VANETs can potentially minimize the effects of disasters. Circumstances such as floods, flash floods or earthquakes, searching and rescuing of victims, communication among teams, communication between emergency services or base stations are some possible applications of VANETs in disaster situations. The basic communication of VANETs is approximately same with MANETs, although there are also significant variations in the routing protocols and broadcasting. However, having higher mobility than MANETs, VANETs require a rapid medium entry to achieve speedy communications between the nodes (vehicles). MAC protocol IEEE 802.11p is more desired than the conventional IEEE 802.11a/b/g. Within IEEE 802.11p some levels of priority are specified. In VANETs cases, Roadside units (RSUs) are the static nodes of the networks, which provide wireless entry to all onboard units within its coverage. In opposed to, VANETs are distinguished by V2V and V2I communications. In disaster scenarios, RSUs are probably to be harmed or inappropriate, therefore V2V communications could be regarded as the major applications of VANETs. However, for large disasters, V2I communication also applicable by establishing base station (Reina et al., 2015).

2.2.2.6 Aerial Aware Infrastructure-less Network

FANETs introduce a new paradigm of wireless communication which engaged in wireless-based vehicular mobility with networking capabilities. It builds mainly UAVs (Sahingoz, 2014) and governs the autonomous movement of the UAVs with supporting UAV-to-UAV communication (Z. Zheng et al., 2018). In disaster areas, where infrastructure network is absent, the need to quickly establish a network between teams can be answered by rapidly deploying UAV as a relay node. To achieve such a complex task, UAVs require a high level of coordination and a robust inter-vehicle communication network in an ad-hoc manner.

FANET network infrastructure enables disaster conscious mobility model wherein the UAV team act as nodes and relaying message collaboratively. Dealing with characteristics, for example, the altitude of the UAV node, satellite geometric dilution accuracy, visibility of GPS and real-life atmosphere, is important for the model (Mukherjee et al., 2016). A number of articles are investigated FANET in disaster-affected areas. Such as Flying Real-Time Network (FRTN) and its communication feasibility is shown in (Micheletto et al., 2018) for disaster scenarios. Deploying drones as flying witness units can act as communication gateways among first responders that will cover different spots at the disaster-affected area. Thus, the ad hoc based UAV can even be seen as a FANET format.

2.2.2.7 Opportunistic Aware Infrastructure-less Network

DTNs consists of nodes with restricted resources such as limited power and memory capacity. Figure 2.5 shows the DTN routing of Cognitive Wireless Network structure. It is infrastructure-less networks wherein wireless nodes are not continuously connected by single or even multi-hop. DTN nodes adhere to the store, carry and forward technique to deliver messages from origin to destination. That means when a node gets a message, the node keeps it into his memory until the node finds another node to exchange this message with. On account of this, the nodes of higher mobility enhance the possibility of node meets and therefore the possibility of delivering messages. Such kind of communication network is necessary for providing non-time-sensorial data (Pham et al., 2018).

DTNs could be good a candidate for emergency communication networks, particularly in the area where The huge disaster destroyed network infrastructure in disaster terrain and the disconnection of communication triggered various problems like as the suspension of search and rescue missing people. In such a weak environment DTN is considered one of the most workable method. An occasionally-connected network DTN can be a good solution in this scenario where some part of network isolate for flood disaster, worked as an opportunistic network. This type of connection is called intermittent connection.

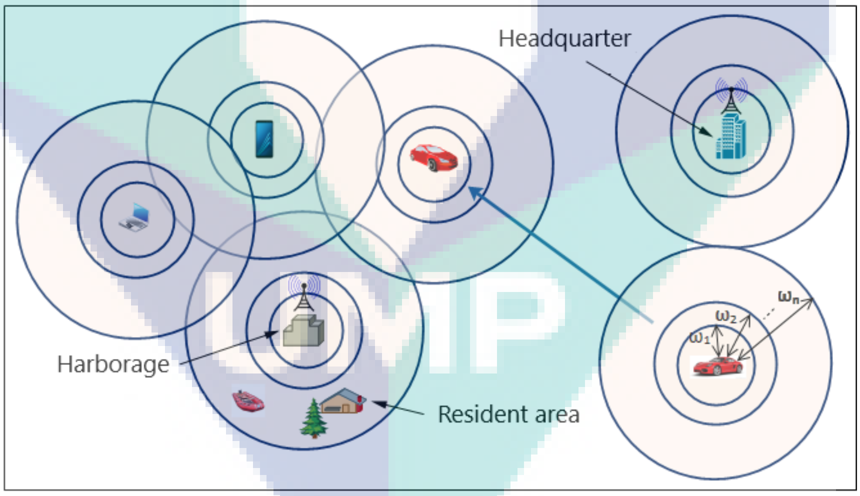


Figure 2.5 DTN routing of Cognitive Wireless Network.

In (Asuquo et al., 2018), the authors contemplate the use of DTN for emergency communications in disaster scenarios. Hence, a decentralized trust management scheme (DTMS) is designed for mobility aware of DTN. This proposed scenario calculates direct trust by integrating the forwarding attitude of nodes with their power consumption rate. Then, second-hand data from nearby nodes are combined to model recommendation trust. Finally, the recommendation trust incorporates indirect trust, recommendation familiarity, and credibility which improve the all-around recommendation trust with cancel out unethical recommendations. Their extensive simulation shows that DTMS practically mitigate routing misuse of DTN in the post-disaster scenario. Table 2.1 shows the specifications of different ad hoc networks. This table provides some key features about the mobility model, propagation model, functionality, mobility, topology and so more.

Table 2.1 Showing the key comparison among different CPS-aided infrastructure-less communication protocol used on SAR in flood.

Ad-hoc network types	**MANET**	**DTN**	**VANET**	**FANET**
Node mobility	Low	Medium-unexpected	High	Very high
Radio propagation model	Very close to ground, LOS not available for all cases.	Very close to ground, LOS not available for all cases.	Close to the ground, then LOS is accessible for all cases.	High above the ground level, LOS is accessible for most of the cases.
Mobility model	Arbitrary	Arbitrary	Steady	Arbitrary
Main functionality	Real-time communication	Nondelayed data Communication	Real-time co-mmunication	Real-time communication
Topology change	Slow	Slow	Average speedy	Fast and speedy
Node density	Low thickness	Medium-low	Medium depth	Low thickness
Power consumption and network lifetime	Require of energy-efficient protocols.	Require of energy-efficient protocols.	No needed	No needed for small UAVs, but required for mini UAVs,
Computational power	Limited	Limited	Average	Very big
Localization	GPS	GPS	GPS, DGPS, AGPS	GPS,AGPS,DGPS, IMU

2.2.3 Aerial Network Communication in Flood

Since the past few years, trained rescuers have considered the adoption of novel and advanced technologies to assist in the events of disasters in order to save more victims. The aerial communication network is one of them. Aimed to tackle communication challenges such as increased network coverage in rural, remote locations, improved line-of-sight (LOS) conditions, a certain variety of disaster-oriented aerial communication networks offer promising performance to enhance communication resilience. In the last few decades, remarkable progress in microelectronics has permitted the decrease of wireless communication equipment size and weight. Furthermore, new technologies and communication materials have made it easy to separate baseband unit (BBU) and remote radio head (RRH) therefore creating the equipment conveyed by aerial platforms much compact and light. This offers the valuable potential for trained rescue professionals and industries to develop and deploy aerial communication networks where aerial platforms that embed wireless communication capability are implemented to provide mobile wireless access points for terrestrial network nodes (Gomez et al., 2016). In this section, we have described the wireless network based on various aerial base stations (ABS) for an emergency wireless communication network in disaster scenarios.

2.2.3.1 Drone Base ABS

Unmanned aerial vehicles (UAVs), commonly known to as drones, is an airplane except for a human pilot overboard and remotely controlled. The use of drone is increasing rapidly across numerous civil applications. Developing an emergency communication network for SAR mission in the disaster-catchment areas is one of them. In disaster-affected areas, maximum cellular base station and roadside units (RSU) can fail because of physical destroys or power outages. As a consequence, it can be impossible or very risky to build communications among first responders for SAR activities. In the same way, owing to damage of RSU vehicle-to-vehicle communication may also down due to the scarcity of neighbors into less vehicle density circumstances or collisions into more vehicle density in disaster terrains. To overcome these issues, drones can be furnished with communication equipment and establish to appropriate positions in the disaster areas, so they could operate as aerial base stations (He et al., 2017; Jia & Zhang, 2017). Lower altitude drone-aided systems are more affordable by allowing on-demand operations. It also makes faster the deployment of base stations, more flexible reconfigure for the sake of their fully manageable mobility, and possible to have much better communication channels owing to the line of sight connects compared to the high-altitude based or terrestrial communication techniques. Furthermore, for observing and evaluating particular disaster, drones may provide big assistance because they may get into some areas which are hard or impossible to reach for the first responders (Shakhatreh et al., 2018).

Deployment issues: Although drone provides a rapid deployment possibility as aerial mobile stations, therefore, have some key issues that should be maintained for better service. Such as:

- The efficient placement of drone is one of a prime issue for aerial base stations. The drone mobility in the vertical and horizontal dimension, the differences among the air-to-surface and terrestrial channels make the location of the UAV to diverge from the location of terrestrial stations. 3-D optimal placement formula decoupled the horizontal dimension in the vertical dimension that makes easier the placement problem except for any optimal loss and enhances the number of network covered users utilizing the minimal transmit power. So the network may benefit the highest (Alzenad et al., 2017; Bor-Yaliniz et al., 2016). Polynomial-time algorithm using consecutive MBS placement is also a good solution to find victims in disaster areas who are carried on mobile devices. Hence MBSs are located sequentially starting upon the area enclosure of the uncovered ground terminals along a spiral route to the center, whilst all ground terminals are covered. This algorithm provides wireless network coverage with a minimal number of MBSs (Lyu et al., 2017).

- Generally, drones are battery powered and the lifetime of the drone-BSs process is by energy efficiency. Therefore, it should be considered in the standpoint of the system. Optimal placement of drone-BSs in accordance with user density, the condition of the environment and expected to transmit data rates are a common strategy to enhance emergency efficiency. Moreover, the power consumption of board circuits, rotors related, computational chips and the probable mobility energy consumption of drones can also impact the duration of network (Jiaxun Lu et al., 2017). The employ of drone-recall-frequency (DRF) concept characterizes the duration of mobile drones network where maximum lifetime is equal to minimum DRE described in (J. Lu et al., 2018). The efficient placement of drone-BSs minimizes the DRF and pattern formation module-based framework ensure the accuracy of drone-BSs. Then accurate pattern formation and decision model (sequential-Markov-greedy decision) on dynamic placement maximize the lifetime of drones network. In this regard, the probable mobility power and onboard circuit power are considered.

- A compatible channel model is a fundamental requirement to make an exact prediction of the work in ABSs. In (Sharma et al., 2018) has concentrated on a path loss and also shadow fading channel model which is generally used to illustrate the propagation among an ABS and a user on the surface. A commercial simulator, 3D raytracing is used to extract the main parameters used in the model and the LoS/NLoS probabilities as a function of the transmitter elevation angle and height.

Applications: The authors in (Merwaday et al., 2016) consider the throughput coverage during natural disasters for public safety networks by the utilize of UAV-BSs. They applied a genetic algorithm to optimize the placement of UAV-BSs and proved that the throughput can be improved fifth percentile of the network by optimally locating of UAVBSs. In (Kumbhar et al., 2018) and (Kumbhar & Simran, 2017) investigated the establish a mission-critical communications with deploying UAVBSs during the event of disasters to the emergency safety infrastructure where they used UAVBSs into LTE-Advanced heterogeneous networks by applying the technique of 3GPP Release-11 further-enhanced inter-cell interference coordination and cell range expansion. UAVBSs using LTE-unlicensed technology is analyzed in (Athukoralage et al., 2016) to enhance broadband throughput in disaster scenarios and aims to develop a framework for load balancing between UAV-BSs and WiFi access points and propose a regret-based learning dynamic duty cycle selection method for configuring the transmission gaps in LTE-U UAV-BSs, to make ensure a satisfactory throughput for all users.

2.2.3.2 Airship Base ABS

Airships are high altitude platforms (HAPs) that utilize lighter fuel to float in the air and classified as aerostatic platforms. They have characteristics of being more versatile in terms of size, weight, rapid deployment-redeployment features, and modular design. This technology allows payload communication equipment to lift and users can communicate using a fixed station platform 21 km above the earth and coverage can get to a region until 1,000 km in diameter. These kinds of aerial platforms can be decorated with a location beam antenna for Wimax/4G and digital broadcasting that provide high-speed data traffic for voice, video conferencing and broadcast TV and TV on-demand, digital radio, interactive TV (iTV), etc. Airships can be chosen as an aerial platform for the emergency network in the disaster area to the following characteristics:

Rapid deployment: HAP station technologies could rapidly be deployed, redeployed and upgraded. It is packaged in an easy modular product range and can be formed step by step by user and market demand.

Low cost: Airship platforms are much cheaper compared to existing infrastructures (terrestrial wireline and satellite systems).

Proximity: HAPs allow different transmission technologies to operate on the same platform-including telecommunication, broadcast, TV and radio, local GPS, VoIP, and remote sensing.

Coverage: HAPs can coverage achieve up to 1000 km in diameter and can act as a stratospheric node of a larger network with satellite and ground portions.

Applications: Some works have been done based on airship HAPs. For example, in (Dong et al., 2015) integration of HAPs and satellite networks are mentioned for emergency communication in a disaster scenario. Hence the authors described an emergency communication network when a disaster happens, that comprises three segments, i.e., 1) space segment, which is formed by a general-purpose satellite operating within the geosynchronous (GEO) orbit, 2) near the space segment, which comprises several HAPs that are launched around the disaster-affected area, and 3) ground segment, which consists of two sub-segments, namely clients sub-segment and center network sub-segment. Remote sensor devices, rescuers terminals and multi-radio portable devices located within the vicinity of the victims are clients that support communications via WiMAX/LTE and DVB-RCS with the HAPs and satellite, respectively. The primary responsibility of the central network sub-segment is to perform routing and interchanging data with the government and nationwide rescue organizations.

2.2.3.3 Helikite Base ABS

As the name implies, helikite combines a helium balloon and a special kite. It is incredibly versatile and overcomes the shortfalls of general tethered balloons, kites and UAV's blimps. Aerodynamically sound tethered helikite exploits both helium and wind to lift. The shape of the ballon is usually oblate-spheroid. To combat the blowing wind, the aerodynamic lift is indispensable and even little helikites allow to fly at higher altitudes. Moreover, winds at high altitudes can push normal balloons to the surface. This is a unique design of aerostat. Exploiting both the wind and helium to enable lifting the helikites in order to fly at high altitudes and carry more payload compare to other aerostats in different weather conditions. Helikites does not need constant electrical power to drive a ballonet. Other advantages include relative affordability to purchase helikites (Allsopp, 2014). and fewer legal obstacles as compared to other aerial platforms (e.g., manned aircraft or UAVs). Countless are operated globally, used over land and sea with both military and civilians. In the European context, agile and responsive helikite systems have been designed and experimented to lift 4G-enabled base stations during disasters, which will facilitate information exchange for the emergency service.

Deployment issues: This type of aerial base station is consists of aerial and terrestrial segments where implement LTE-A technology.

Aerial segments**:** Helikite is being critical material in an aerial segment that contains the antenna, battery, remote radio head (RRH) and so on. The absolute (Chandrasekharan et al., 2016) use a $34m^3$ medium sizes helikite which are extremely movable, fast to establish, and easy to operate. The length and wide of the helikite are 6.5 m and 5 m and has a genuine helium for aerodynamic lift among no wind. The RRH supports a spacious frequency range from 70 MHz to 6GHz. The total power consumption is 1.7-1.8A and consisted of flexible software defined radio (SDR) platform. The SDR formed of a stacked digital interface card and radio frequency front-end that makes it able to manage two radio frequency transceivers by 2-antenna duplex operation from 3-50 MHz range radio frequency signal bandwidth.

Terrestrial segments**:** The baseband unit (eNB-BB) is the main element of the terrestrial segment. It connects with the distributed EPC for providing a full end-to-end communication solution. It can be easily deployed in outdoor environments by a base-band cabinet. This baseband cabinet carries all the essential elements of the AeNB subsystem. These elements are: 1) Micro TCA box which receives the board of eNB baseband for PHY and MAC layers, 2) A server wherein run EPC software and also SIP server software, 3) folding keyboard and screen that make the easy access in the server for fulfilling registration of fresh MM-UEs, and 4) rack for powering, cabling and routing activities of the earthy segment. The baseband cabinet is attached to the RRH by optical fiber on one hand and to the deployable Ka-band satellite terminal via Ethernet on the other (Gomez et al., 2016).

Applications: There are numerous examples in the literature of aerial base station on helikite for emergency communication networks. Such as, the authors in (Chandrasekharan et al., 2016) design and implement aerial base station using helikite to provide wireless coverage in the consequence of large-scale disaster integrated with LTE-A and satellite networks which is fastly rolled out and reliable. In (Gomez et al., 2016) describe detailed the technical solutions about the higher capacity and coverage abilities of opportunistic networks for inhospitable areas after a disaster. Helikite as eNBs, LTE-A, and satellite networks are predominately adopted in the description of this opportunistic networks. Kandeepan et al. (Kandeepan et al., 2014) illustrate hybrid aerial-terrestrial network communication for emergency operation in large scale natural disasters where helikite used as low altitude platforms (LAPs). The article focuses on energy-efficient function and proposes a real-time adapted transmission scheme that dynamically selects the best link for enabling energy-efficient communications based upon the channel conditions in hybrid aerial-terrestrial networks. Hence the cooperation among mobile terrestrial terminals on the surface improves the energy efficiency in the uplink which depends on the temporal behavior of the aerial and terrestrial uplink channels. Authors in (Gomez et al., 2015) are intended to establish temporal large network coverage in the disaster scenarios based on helikite aerial platforms. The proposed network architecture is combined of satellite, aerial and terrestrial communication segments where focusing the aerial segment in terms of cell coverage and capacity for LTE system. Table 2.2 summarizes the abilities of most appropriate aerial platforms are available for purposes of applying aerial platforms by considering the key features. the fundamental of aerial platforms use was provided large-area wireless coverage. The raised look-angle provided through aerial platforms gives significant communication benefits contrasted to the terrestrial equivalents that demonstrated in this table. The key features show among of these aerial platforms helikite is the good choice for SAR operation however this platform is not available in the market.

2.2.4 Technology Standards

Recently, around the world, most of the public safety organizations have replaced their legacy wireless communication equipment with new digital wireless communication systems based on analog technology. Three types of standards have become prevalent: TETRA and TETRAPOL (i.e., European standards) in Europe and APCO 25 in USA (i.e., a USA standard). These are known as land mobile radio system (LMRS) and LMRS is the nucleus of the currently developed PSNs. LMRS is a terrestrially-based wireless communication system composed of mobiles or portables, for example, walkie-talkies or two-way digital radios. The main objective of the LMRS system is to provide mission-critical communications by integrating voice and data service. These networks and devices are being utilized in various emergency safety organizations for emergency feedback.

2.2.4.1 TETRA

TErrestial Trunked RAdio (TETRA) is a multi-function mobile radio communications standard for digital private mobile radio (PMR) systems developed by the European Telecommunications Standards Institute (ETSI). The narrowband telecommunication standard TETRA is particularly designed to accomplish the communication demands from public safety and security (PSS) agencies for emergency services (Delgado & Santiago, 2014). Secure voice and data communication and extensive features of TETRA make ensure the adaptability required to meet the distinctive requirements of PMR users. It is basically confined to 1-3 layers of the OSI model. The system of TETRA is intended to operate in existent VHF and UHF mobile radio frequencies.

The TETRA standard specifies several kinds of air interface, which are voice plus data (V+D) air interface, direct mode operation (DMO) air interface and packet data optimized (PDO) air interface. The (V+D) is the most frequently used mode and the primary V+D standard is now identified as TETRA release-1. Other modes are also supported by TETRA radio system under this release.

The V+D allows switching among voice and data transmission. Using the same channel but different slots of voice and data could be transmitted (Dunlop et al., 2013). The V+D provide an extensive range of teleservice, carrier services, and supplementary services pertinent to a combined data and voice capability such as i) advanced and rapid voice call and group call services among the rescue teams and organizations, ii) pre-regarding priority call services, choose the highest priority emergency call and provides the maximum uplink priority as well as maximum priority access for network resources. The lowest priority call is fallen to manage the emergency communication, when a network system is busy, iii) call retention, under this service selected radio end-users will be protected from forcing down the network during busy times of pre-regarding emergency calls, iv) priority call service, when the network remains busy, this service permits access to network resources according to terminal users call priority status. During occupied periods such service is quite useful in delivering the different grade of service levels since in TETRA has 16 levels of priority. For instance, front line rescuers provided the highest level priority in an emergency network to maintain the highest level of service, such as in case to reach the victims before deadline, v) area selection service, that defines the operation areas for users, vi) late access, This service offers continuous update call progress about join or leave in a communication channel during operation. As an example, if a user activates their own TETRA terminal it will automatically divert to a communication group call by the control channel, though already a call is in progress. Likewise, if the user's terminal has become outside broadcast coverage, such as in a tunnel, it will also divert to a communication group call by the control channel, though already a call is in progress, vii) data service and etc (ETSI, 1997; Ketterling, 2003).

In DMO, voice and data communication are support directly and offer both single-to-single and single-to-multiple transmission. The subscriber units can directly communicate with one another without using base stations and able to rapid call setup for critical communication. In this case, the mobile radio requires to stay into coverage of one another (Lehner et al., 2013). The emergency situation in the place can happen limited signal potency or in the area where no radio signal is present, TETRA DMO mode is provided there an alternate communication. The DMO is specifically applicable in emergency scenarios wherein effective local area communication between rescue team members on certain disaster locations is required (Hrovat et al., 2008). DMO is not allowed clear or encrypted calls and full-duplex communication (Kumbhar et al., 2017).

PDO standard is particularly designed and optimized for solely packet data communication. Like TETRA V+D, it uses a similar 25-KHz carrier separation as well as pi/4-QDPSK modulation. The data rate of PDO is little bit higher compared to V+D. Moreover, V+D is more flexible than that of PDO because It permits voice and data transmission both in circuit mode and connectionless mode. The TETRA PDO mode also provides unlimited mobility with the handover and full roaming capability. This mode is particularly well suited where location base service and large volume of data are necessary for mission-critical communication (Ketterling, 2003).

Release two, is the TETRA new release, at 2005 which improves the already existing efficiency of TETRA and providing this following services: i) TEDS ii) TMO range extension iii) MELPe voice codec iv) AMR voice codec. TETRA Enhanced Data Service or TEDS is the major enhancement by TETRA release 2 that provide high-speed data service using various radio frequency channel bandwidths as well as data rates for convenient usage of PMR frequency bands. TETRA TEDS is entirely backward compatibility with Release one and allows easy of migration from TETRA Release one to TETRA Release two. It has increased the performance level significantly to fulfill the growing demands of users. TEDS-allowed networks offer to assist for real-time duplex voice and video streaming in emergency situations between rescue members and emergency responders for enhancing operation activities as it provides a higher level of data service. Such as an emergency disaster scenario where need to monitor a remote victim might require big data rate for assisting real-time bidirectional voice and video communication as well as telemetry. This type of scenario, TETRA

TEDS increased data service could play a significant role with supporting the applications which require high data rate as like location services and multimedia (Kumbhar et al., 2017).

In the case of Trunked mode operation (TMO) range extension, the maximum range of TETRA releases one was 58km. However, the greater distance was needed for a lot of applications such as air-ground-air communications. To cater this, TETRA release two has been modified the uplink and downlink bursts and guard times of release one and enabled the TMO to extend up to 83 km for air-ground-air services. Similarly, the improvement of Adaptive Multiple Rate (AMR) Voice Codec has been recognized as being capable to provide significant benefits for some TETRA applications. The AMR codec using in 4.75 kbps only mode for TETRA radio and has been selected for potential future applications. Lastly, the improvement Mixed Excitation Liner Predictive, enhanced (MELPe) Voice Codec has been standardized for military communication applications and used for immunity to high background noise and appropriate voice quality efficiency (Gray, 2019).

2.2.4.2 TETRAPOL

TETRAPOL is an open, digital, professional cellular trunked radio technique for digital voice and data communication utilized by public security and military forces throughout Europe. It is developed by EDAS telecom (previously MATRA). In 1988, while TETRAPOL was chosen as the first implementation regarding an extensive digital professional mobile radio (PMR) network for the world's, its subsequent favorable outcome has been unbeatable around Europe as well as all over the world and becoming used with a wide range of public safety, civilian, military forces, and more other security organizations. At present 60 TETRAPOL networks implemented or in the procedure of being implemented in 28 states.

It is built for a particular purpose of PMR technology, which designed to fit these most demanding of users. TETRAPOL is suitable for day-to-day functions, providing individual (single-to-single) and group (single-to-multiple) voice services and complemented with a growing number of data services. The robust TETRAPOL system will not let down in an emergency situation, either it is a terrible natural disaster (such as flood, earthquake, hurricane) or a man-created incident.

TETRAPOL is entirely different from the TETRA standard, although the name of the product is the same as TETRA. Like TETRA, TETRAPOL provides messaging, broadcast calls, group calls and more, however, in particular conditions TETRA provides better performance compared to TETRAPOL. TETRAPOL usages Gaussian Minimum Shift Keying (GMSK) modulation in the place of pi/4-QDPSK utilized by TETRA. The bit rate of overall modulation is 8 Kbit/s utilizing binary GMSK modulation. The GSM also used this modulation system and the advantage is that the simple and comparatively cheap transmitters could be applied with a higher level of efficiency (www.tetrapol.com).

TETRAPOL is established upon a fixed network infrastructure and the coverage depends on the deployment of the infrastructure. Generally, a base station provides coverage within a radius of a few kms depending on the disaster terrain. A TETRAPOL base station may handle until 24 radio channels. The TETRAPOL channel access is based on FDMA multiplex approach with a 12.5 kHz channel spacing. TETRAPOL has been developed on the base of emergency operational requirements and Like TETRA, TETRAPOL is currently used in numerous scenarios such as large natural disasters (e.g., flood, earthquake), emergency situations in urban areas, border area and so on. During large natural disaster management normally includes the different types of responders from rescue teams, fire-fighters, NGO, police, and military across a large geographic area, where TETRAPOL can be used with establishing an emergency network within a short time (Baldini et al., 2013).

2.2.4.3 APCO-25

APCO-25 is a set of standards for digital radio communications for public safety and service applications developed among others by the Association of Public Safety Communications Officials International (APCO). It is also familiar as project-25 or P-25 and widely used for LMRS based radio communications (Kumbhar & Güvenç, 2015). APCO25 is standardized by TIA (Telecommunications Industry Association) and mainly used in the USA. It is based upon FDMA access technique as well as QPSK-C modulation. This technology enables to provide numerous services such as individual call, group call, wireless data, incorporated voice and data, encrypted security, dynamic emergency and grouping call. In addition, APCO-25 APCO-25 keeps a backward coherence with the analog radios. Thus, APCO-25 equipment can perform directly both in analog and digital mode with different APCO-25 radios at an equal frequency (Chavez et al., 2015). The APCO-25 allows emergency service agencies and allowing them to reliable inter-agency and intra-agency communications. As well as APCO-25 provide enhanced features with the equipment and abilities based on emergency needs. APCO-25-compliant technology has been deployed in two main phases, where improvements have been periodically introduced.

In phase one, radio systems can operate at 12.5 KHz all modes such as digital, analog, or mixed-mode with FDMA access technique. The radios in phase 1 use continuous 4-level frequency modulation (C4FM) method, which is a special kind of 4FSK modulation for digital transmission in 12.5 KHz and producing 9600 bits/s total channel throughput. APCO-25 phase 1 techniques are backward compatible as well as interoperable with analog systems. In phase 2, a 2-slot TDMA system is introduced which provides two voice channels in a 12.5 KHz band allocation.

Table 2.3 demonstrates the technical features of legacy LMRS. This table provides several details about channel bandwidth, frequency bands, modulation technique, access method, peak data rates, professional use, and supported applications. LMR emergency networks provide voice data communication, narrowband data, and wideband data services. nevertheless, they can not support broadband applications, that no longer satisfies emergency public safety stakeholders. In this regard, LTE technology is selected by many, including the U.S. Federal Communications Commission (FCC), for deployment in the broadband portion of the PS allocated spectrum. However, there are challenges regarding the use of LTE for mission-critical applications. In the past, LMR has been used in emergency situations by voice services, but data connectivity is becoming increasingly important to support more precisely SAR operation. Therefore, different organizations are using different communication systems during an emergency disaster crisis. Moreover, LMR systems are the soul of the currently developed public safety networks.

Table 2.2 The specifications of legacy public safety networks

Performance components	TETRA Release 1	TEDS	TETRAPOL	APCO-25 Phase 1	APCO-25 Phase 2
Developing organization	ETSI	ETSI	Airbus Defence and Space	TIA	TIA
Release date	1995	2005	1980s	1995	2010
Vendor support	Multiple	Multiple	Single	Multiple	Multiple
Access method	TDMA (4 slots)	TDMA (4 slots)	FDMA	FDMA	TDMA (2 slots)
Modulation	π/4-DQPSK	4/16/64-QAM	GMSK	C4FM	C4FM
Channel bandwidth	25	25, 50, 100, or 150	12.5	12.5	6.25
Frequency bandwidth	UHF, VHF, or 800	UHF, VHF, or 800	UHF, VHF, or 800	UHF, VHF, 700, 800, or 900	UHF, VHF, 700, 800, or 900
Applications	Voice and NB data service	Voice and WB data service	Voice and NB data service	Voice and NB data service	Voice and NB data service
Professional use	PS and others	PS and others	Only PS	Only PS	Only PS

2.2.5 Performance Measurement Metrics

A simulation study has been carried out to measure the performance of the network based on the standard network performance metrics like packet-delivery-ratio (PDR), overhead and delay. The definition of the considered metrics are providing below:

PDR: PDR is defined as the percentage of the ratio between the number of packets received by the destination node and the number of packets generated by the source node. Mathematically, it can be defined as:

$$PDR = \frac{P_{Received}}{\sum_{n=1}^{N} P_{Generatedi}} 100 \qquad 2.1$$

Where, $P_{Received}$ the number of data packets received by the sink nodes, $P_{Generated}$ is the number of data packets generated by the source nodes.and n represents the number of sensor nodes.

Overhead: Overhead is the total number of routing packets transmitted during the simulation. Sending more routing packets consumes more power. Sending more routing packets also increases the probability of packet collision and can delay data packets in the queues. The overhead is the ratio between the total number of Data Packets and the summation of the total number of Data Packets and the total number of Signaling Packets. The more overhead means the performance of the network is poor. Mathematically, it can be defined as:

$$\text{Overhead} = \frac{N_D}{N_D + N_S} \qquad 2.2$$

Where, N_D is the total number of routing packets and N_S is the total number of delivered packets.

Delay: Delay is defined as the average time it takes a data packet to reach the destination. This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, transmission time and delays induced by routing activities. This metric is calculated by subtracting time at which the first packet was transmitted by the source from the time at which first data packet arrived at the destination (the sum of the time spent to deliver packets for each destination). Mathematically, it can be defined as:

$$\text{Delay} = \frac{\sum_{n=1}^{N} (A_i - S_i)}{N} \qquad 2.3$$

Hence, i-th data packet that successfully reached the destination where A_i is the arrival time and S_i is the sending time.

2.2.6 Challenges

The following challenges should be considered in order to develop a communication infrastructure with IoT-aided SAR in flood management system.

Rapid Deployment: In disaster scenarios, such as, during floods or earthquakes, conventional communication infrastructures are damaged or partly damaged. Therefore, rapidly deploy an emergency network is a crucial task for connectivity among the rescue teams and to allow the first responders to report their findings and coordinate their rescue tactics in the incident area. So, from the networking perspective, the primary goal is to restore connectivity at least temporarily to provide such communication services. The design of such a network should also allow for rapid, scalable, flexible, and durable deployment with minimum human intervention (Miranda et al., 2016).

Designing and model: The design of CPSs enabled mission-critical system is more challenging than either pure cyber or physical systems. This is because, such as, hardware description language or programming language is adequate to implement desired behavior for a pure computing (cyber) system. nevertheless, for CPSs, the expected behavior of network components needs to be specified in terms of their action on the physical environment. Therefore, a unifying framework is required for modeling them, which allows easy interfacing and consistency. Since the real world is concurrent, CPSs also need to be concurrent, and this aspect is reflected right at the modeling and architectural phases (Khaitan & McCalley, 2015).

Data rate: In networked SAR model, a large number of components acquire and exchange real-time videos and images. A sufficient data rate must be supported to enable such a real-time data rate in the network by the selected wireless technology. In a fruitful rescue mission, live videos and images should be timely interchanged among the rescue actors. Therefore, higher data rate and low latency is essential QoS metric that must be strictly guaranteed. Among the existing wireless technologies, such as ZigBee and XBee are not able due to their low data rate as their maximum potential data rates are only 250 kbps. the existing other standards detailed in Table 2.1 can comfortably satisfy the requirement and attain higher data rates also support for low latency requirements, and they are consequently preferred for the CEMCS.

Coverage: In disaster scenarios, the range of patrolled areas can around several kilometers. This is because the collaborative network coverage should be more or equal than the patrolled area where Line-Of-Sight (LOS) transmission always not be possible. Therefore, the selected standard should support Non-LOS, with long-distance transmission coverage. Because of this, selecting an appropriate technology is another important issue among the existing technology.

Mobility: Mobility is essential to deploy an efficient SAR model, wherein almost all the rescue agents are non-static with diverse mobility characteristics. Some agents move at a low speed, for example, HRs, ground vehicles, and drones, whereas other agents can move quickly up to around 30 m/s for example rescue copter. Therefore, the coordination of different components is an important issue for smooth operation. Since the collaborative network lies between ground and air, and the typical two-dimensional ground vehicular movement pattern, the overall mobility dynamics of the collaborative network nodes spans three dimensions. Subsequently, the network standards can require reconfiguration in terms of individual elements to support the needed three-dimensional mobility model of flood network.

Energy: In any hostile network environment energy is one of the significant issues due to there minimum supply of energy sources. The maximum components in SAR network architecture are battery-powered. Therefore, It is essential to reduce the energy expenditure and select the energy-efficient components for extending the component lifetime as well as the network lifetime.

Operating band: Selecting the operating band characteristics of a particular wireless standard for the SAR network components is also an important factor as in a licensed band operation needs license cost. A cognitive radio approach can be built a given standard to allow unlicensed users opportunistically to take advantage of temporarily unused parts of the licensed band (Rahman et al., 2018b). ISM (Industrial, Science, and Medical) frequency bands can be an alternative solution by using technologies that operate above unlicensed bands (around 2.4 and 5.8 GHz). Although, this solution should be carefully analyzed with consideration of dispensation to data rate, coverage, resistance to noise and ability to handle interference.

Diffusion: The term diffusion influence the customers to select a wireless standard. When a technology becomes popular, we can securely assume which has been examined rigorously in different scenarios that reveal its abilities, strengths, and weaknesses. Therefore, in the market, the availability of the devices will be higher and they are also financially affordable and trustworthy from a function viewpoint. In this perspective, diffusion can be another influential factor for selecting a suitable wireless standard.

2.3 Related Works of SAR for Disaster Management

Among numerous challenges recognized in developing SAR emergency network, the demand for dependable and high quality communication is unanimous. The authors (Abdallah Jarwan, 2019; Baldini et al., 2013; Kumbhar et al., 2016; Yu et al., 2018) given a detailed overview of the development of emergency SAR communication, as well as results on relevant research domains, highlight the history of safety networks, including LMR and LTE-based safety networks, and discuss the requirements that have to be inherited in SAR emergency network. (Ali et al., 2018) discussed D2D communication for disaster management. The concept of RF-based energy harvesting (EH) is applied to provide the optimal communication route for networks in disaster areas that which minimizes the end-to-end disconnectionA vehicle assists resilient information and network system for disaster management is designed despite of the internet unavailability in (Li et al., 2017). It contains three main components: (1) smartphone apps; (2) mobile stations servers; (3) geo-distributed servers. While there are few works in the literature specifically addressing the communication architecture for disaster management system. These architectures can be adaptable to the circumstances at the event site and resilient enough to operate under undesirable conditions in an emergency. The authors (Ergul et al., 2016) proposed a multi-tier cognitive-communication architecture for natural disasters. Here, the concept of intelligent cognitive gateways (ICGs) is provided the required resilience and adaptation. An ICG is a gateway with multiple interfaces to interact with numerous devices, including sensor nodes, RFID readers, WiFi routers, and so on.

Recently, the UAV network is an emerging technology and researchers are using this in SAR operation. For example, (Arafat & Moh, 2019) analyzed the UAV network for emergency communication. They use swarm-intelligence based localization

(SIL) and clustering schemes in UAV networks. (Liu & Ansari, 2018) presented M2M Communications architecture for disaster rescue based on UAV. The authors (Panda et al., 2019) also used UAV to form an emergency Wi-Fi network and Raspberry PI development board over the disaster region. In this paper, an android application is designed to extend the Wi-Fi network coverage.

The work (Agrawal et al., 2019) considered backbone optical communication networks for disaster survivability and proposed a stochastic model to estimate the impact of disasters on a backbone optical network. Routing protocols and architecture for disaster area network are reported in (Jahir et al., 2019). The purpose of this study is to improve delay, reduce overhead, minimize energy used, sustain movement and increase bandwidth for multimedia applications. In (Bader & Alouini, 2016), mobile ad hoc network is discussed for disaster and emergency response, specifically the bandwidth demand is focused on live streaming in disaster scenarios. The paper (Nakayama et al., 2017) proposed a wired and wireless network cooperation system for quick disaster-response operations. In this case, when the wired communication for leaf nodes of optical tree networks is damaged, surviving leaf nodes relay packets to and from these nodes via wireless bypass routes.

2.4 Comparative Study

Numerous work has been conducted for SAR activities based on existing technologies. Due to vital demand to reduce the fatalities and damage in disaster situations, the develop an emergency communication network becomes a more needful research area nowadays. Consequently, different networking technologies have been used to develop seamless communication to facilitate SAR operation. The comparative study is briefly discussed in table 2.4. The techniques, technologies and application areas, as well as outputs, are discussed in this table. For example, The author (Rahman, 2014b) proposed two-tier network architecture with WiMAX technology for SAR operation. It is a two-tier topology and also considered in alpine areas. Again, the article (Baldini et al., 2014) design an emergency communication system for public protection and disaster relief depend on software define network which added TETRA, WiMAX and satellite communications to support wireless communication. Moreover, WiMAX signal can interrupt weather conditions such as rain, which is very common in flood situations. The data rate is not sufficient for video service in WiMAX that is very essential in modern SAR operation and LOS is required for longe distance. WiMAX is a very power severe technology and needs solid electrical support which is very difficult to provide in disaster situations (Pareit et al., 2011).

(Arafat & Moh, 2018) used UAV network and proposed swarm-intelligencebased localization (SIL) and clustering schemes in UAV networks for emergency communications. On the other hand, (Panda et al., 2019) also proposed UAV-assisted emergency Wi-Fi network for rescue operation. Here, the Raspberry PI (RPI) development board, mounted on UAV is considered to form a Wi-Fi chain network over the disaster region. Another work in (Kobayashi et al., 2017) also considered UAV to expand position estimation coverage area and UWB device is used to find the victim. Although UAV is a emeging technology, moreover it has some limitations such as battery power and flight duration.

The authors (Kaleem et al., 2018) proposed a disaster-resilient three-layered network architecture for PS-LTE. This architecture comprises of an SDN layer to provide centralized control, describing UAV cloudlet layer to support edge computing or to allow emergency communication signal, and a radio access layer. The combined utilization of UAV, SDN, edge computing increase challenges because of utilizing various communication technologies and the important challenge occur while UAV scheduling the joint networking performance optimization of UAV and edge computing. This work (Chandrasekharan et al., 2016) also used LTE-A technology in large-scale disasters where a tethered helikite carry aerial network equipment. One restriction of the existing telecom component and aerial platforms that are not designed to applying AeNB and the positioning of terrestrial segment also influence the flying line of aerial segment if the coverage region of AeNB is large. On the other hand, LTE technology is deliberated as a highly promising applicant to serve SAR activities due to the latest massive development. However, LTE systems are not able of supporting different public safety services to meet their rigid requirements.

Several works have been done exploiting ad hoc networks for emergency SAR network. In (Saha et al., 2015) the authors proposed a 4-Tier ad hoc hybrid network architecture consists of DTN nodes, to build communication in the aftermath of a disaster. They considered the information packet ratio, minimum latency and compliance to the resource limitations to develop such a network. Allowing communication between portable devices such as smartphones, tabs, etc. can be challenging in ad hoc manner and also to apply the protocol stack. Another work in (Minh et al., 2016) proposed a tree-based disaster recovery access network using ad hoc network. Although, ad hoc networks are considered as a good candidate for disaster management activities due to his multihop features, moreover, there are some limitations, such as higher error rate, low data rate, security, energy restriction, etc.

On the other hand, the satellite communication system provides wide coverage and high data rate. Furthermore, it is highly survivable and independent of a terrestrial framework. The authors in (Pecorella et al., 2015) considered the integration of satellite and LTE communication for PPDR operation. It is founded on deployable mobile units that bring LTE network coverage in the disaster region by a satellite backhaul. In (Asuquo et al., 2018) the authors, also used satellite communication with DTN for disaster recovery activities when other network systems are destroyed. Messages with long delay in DTN sometimes bad effect on immediate SAR operation. In addition, satellite design and install need higher cost and only a few countries have satellite communication systems that uninspired the SAR organizations to use that communication network. All the aforementioned works are applicable for SAR operation in emergency disaster situations. Moreover, a crucial problem in post-flood recovery actions is the ability to rapidly establish communication and collaboration among rescuers to conduct a timely and effective search and rescue (SAR) mission given disrupted telecommunication infrastructure to support the service.

contrariwise, we have proposed a collaborative model where collaborative communication network and collaborative searching algorithms are considered together. This is the difference between the existing works. As well as we select TV white space technology for communication network. It is very easy to setup, cheap, license-free and has excellent propagation feature.

Table 2.3 Summary of literature review

Authors	Technology	Technique	Application areas	Simulation	Field experiment	Outcomes
(Rahman, 2014b)	WiMAX	Considered two-tier network topology between human rescuer, and air and surface robots.	Alpine environments	Yes	No	The results ensure the effectiveness of the proposal.
(Kaleem et al., 2018)	LTE	Proposed a disaster-resilient PS network architecture based on LTE that combines of software define network and cloudlets.	Natural disasters and man-mane disasters.	Yes	No	20% less delay and lower energy consumption.
(Oueis et al., 2017)	E-UTRAN, IOPS, LTE	Discussed the general concept of IOPS that include, installation and configuration features, UE, mobility, and security.	Natural disasters	Yes	No	Mentioned some open challenges and research opportunities to evolve the IOPS.
(Ranjan et al., 2018)	LTE	Designed a communication framework using eNB mounted UAVs, and present a novel uplink scheduling scheme named Criticality Aware Scheduling (CAS).	Floods, earthquake, cycle, etc.	Yes	No	Quality of Service (QoS) is improved.
(Yang et al., 2016)	Satellite and MANET	Developed an emergency network based on MANET and satellite network and proposed a new routing mechanism with reactive routing protocols.	Floods, earthquakes	Yes	No	Achieved higher PDR, higher throughput and lower delay.
(Casoni et al., 2014)	Wireless network, star topology	Presented a modular architecture over a wireless link.	Floods, earthquakes, and so forth.	Yes	No	Improve the QoS of latency and throughput in wireless emergency network.

Table 2.3 Continued

Authors	Technology	Technique	Application areas	Simulation	Field experiment	Outcomes
(Chandrasekharan et al., 2016)	Helikite, LTE-A	Used helikites that carry antenna, battery, and RRH equipment and worked as an aerial platform. It is tethered by an optical fiber to the eNB-BB located on the ground that developed an emergency network.	Large-scale disasters	No	Yes	Encouraging result for large coverage and longer lasting solution.
(Nishiyama et al., 2017)	CPS	They developed disaster-durable CPS system and implement a technique, WMN of APs ability to choose the optimal GW.	Large scale natural disasters like earthquake, floods.	No	Yes	The field experiment confirmed the effectivity and feasibility of CPS into disaster situations.
(Asuquo et al., 2018)	DTN	Investigate a DTMS to overcome the store-carry-forward technique during rescue operations.	Large disasters.	Yes	No	Encouraging results that increase efficiency.
(Salkintzis, 2006)	TETRA and WLAN	Propose a solution that allows TETRA terminals to interface for the TETRA Switching and SwMI over a WLAN radio access network, instead of the traditional narrowband TETRA radio network.	Disasters scenarios.	Conceptual framework	No	Expected to better communication system.

2.5 Summary

After devastating natural disasters, getting communication service for SAR operation is difficult due to damage of communication infrastructure or out of use. In these circumstances, many network technologies are not able to provide a communication network and every standard has diverse features. Thus, selecting a suitable technology is a more challenging issue in this situation.

This chapter has presented a though review on different network technologies idea in order to realize an effective collaborative network model, which addresses a sound compromise. Furthermore, the conceptual network framework should be designed in a technology which well capability of data collection can be achieved by rescue victims. Consider the TV white space network in which a promising technology to dynamic spectrum participation. Recently it has been acknowledged as a new opportunity for wireless communication services, because of its low usage (at maximum times and into many areas) as well as brilliant propagation characteristics (Luo et al., 2015). Thus, TV white space has a high possibility to provide better service compared to other technology. Apart from that, it has few challenges such as location error, geo-location database interface as well as unlicensed radio channels can be interfaced. Another challenge is to protect the existing TV channels and also other licensed consumers. But these challenges are avoidable to design a network framework where efficiency is the main issue. Intuitively, the concurrent development of technology further improves network model performance. To familiar the concept collaborative network mode various ad hoc, LMRS, aerial network, satellite, TV white space, and other network technology, their applications and limitations are described in this chapter. It is noticeable that the advantages and disadvantages of these technologies methods have inspired in this research works that will be discussed in the following chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, as presented in chapter two, it could be summarized that the existing network methods could not fulfill the requirement of SAR operations. However, these existing methods have some advantages which are an evolving system from promising technology that assisting SAR activities. Nevertheless, these methods also face some limitations, for example, need collaboration between the rescue agents with promising technology that will optimize the rescue operation in flood-affected area.

The limitations of the existing model and variation features of technologies have motivated this study to propose a system called collaborative cyber-enable mission-critical system which could enhance the SAR operation during flood situation. In this chapter, a detailed methodology of the proposed collaborative CP-AGCM will be discussed. The design concept, architecture, necessary network components, and implemented technology will be discussed respectively. In addition, collaborative search model for multi-victim scenario is discussed with considering other models in this chapter. This collaborative searching model is elaborated by an algorithm. This is the enhancement of expanding neighborhood search algorithm which is illustrated in (Rahman et al., 2018b).

Figure 3.1 is describing the methodology for validating the proposed model. It is the four phases methodology where the first phase is focused on describing the problem statements and objectives by conducting the literature review. It has described in chapters one and two. The second phase concentrates the system design, architecture, components, and implementation which is presented in this chapter. The third phase describes the simulation result, performance, and validation and it is shown in chapter four. finally the fourth phase presents the conclusion and future recommendations that are described in chapter five.

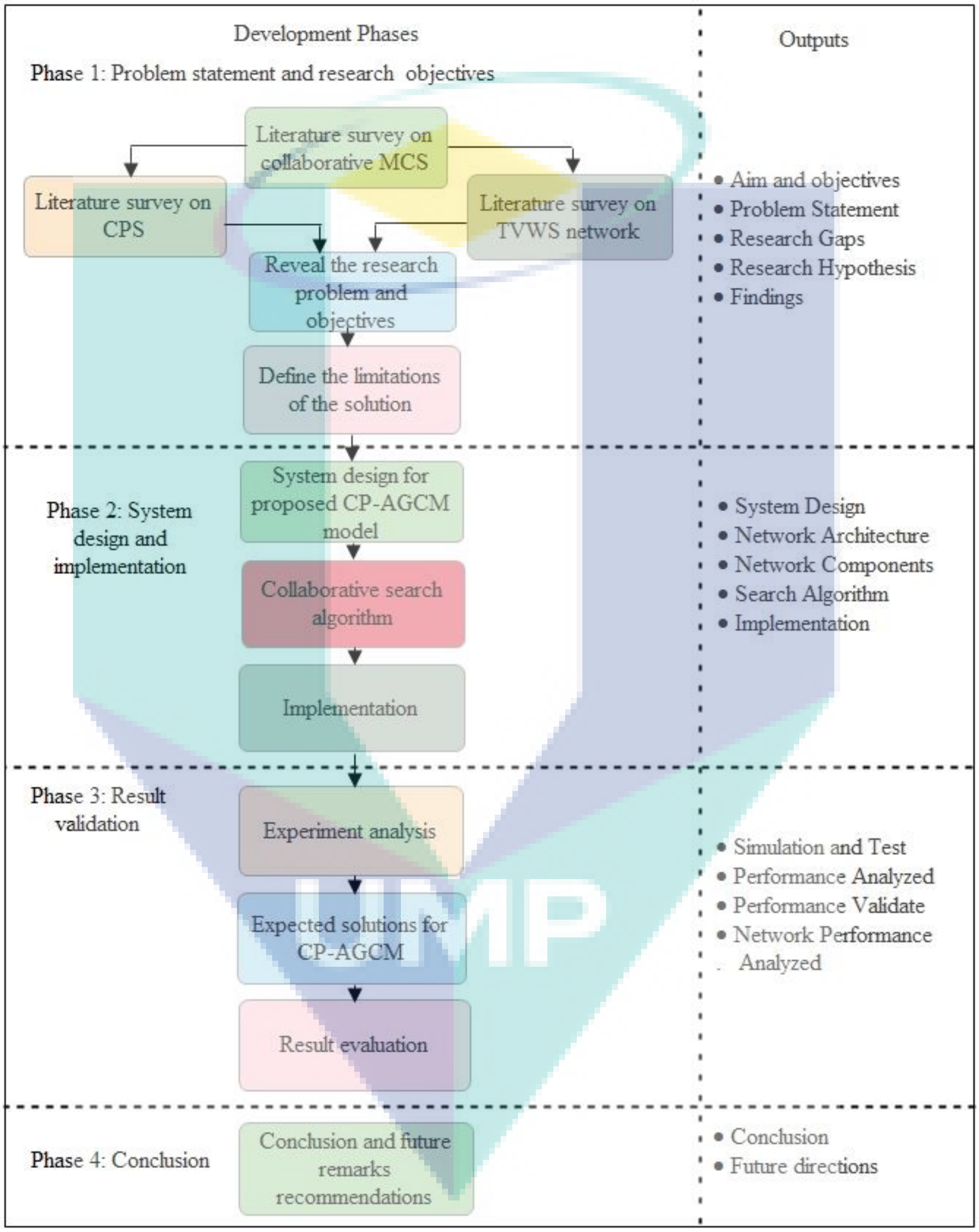


Figure 3.1 Research Methodology.

3.2 Overview of Chysical-Physical Enabled Air-Ground Collaborative Model

The collaborative network is a network that lies in the three space domains (air, land, water) whereby each network element communicates with one another in order to accomplish a set of agreed tasks. In this work, we aim to utilize the collaborative network for a specific application in the flood rescuing system, which aims to retrieve people in distress, provide for initial medical needs and transport them to a safe place. One of the largest challenges for such a system is to establish a resilient communication platform that enables the rapid and reliable exchange of critical information. We envisage to achieve this resiliency using CP-AGCM by exploiting the features of: i) network elements, ii) collaborative network architecture and ii) collaborative search algorithm.

3.2.1 Network Elements of the Proposed Model

The collaborative wireless network for the FRS comprises multiple components, namely, Land Rover (LR), Water Rover (WR), Long Range Manned Air Vehicle (LRMAV), Short Range Unmanned Air Vehicle (SRUAV), Human Rescuer (HR), Regional Control Center (RCC) and Control Center (CC). A collaborative effort of these components would assist in responding rapidly and accurately in the flood victims' rescuing missions. The roles and tasks of these components are discussed in the following.

1) Human Rescuers: A human rescuer is an expert of a specific rescuing mission and has specialist cognitive abilities. They are involved in the direct rescue mission. The rescuers are able to go to the door of victims and rescue them if necessary. They can carry Portable Communication Equipment (PCEs) to communicate with their team through an access point, which is installed in the land rover or water rover. The success of the rescue mission depends on rescuer efficiency and responsiveness.

2) Drone: The objectives of this aerial vehicle are to collect information from the flood-affected area and send it to the human rescuers. It is decorated with high exploration cameras and transceivers, which are used to support for collecting and forwarding information in the disaster area. It functions as extended flying eyes of the rescuer which assist in monitoring and searching

over the surrounding environment. The ability of drone is to fly very closely to the ground for a closer micro detection of victims in the flood area as well as highly movable and agile in its corresponding territory.

3) Water Vehicle: The water vehicle specifically works together with the rescuers and drone to rescue victims in the water-flooded area. It is equipped with communication equipment that enables the exchange of information with other teams and a regional control command. The vehicle team collect information through the use of drone and take actions based on the acquired messages. The water vehicle is able to work in both shallow waters and fast flowing water conditions.

4) Land Vehicle: The primary objective of the land vehicle is to rescue in a shallow flood water condition and muddy areas. It is wirelessly connected to the rescuers so that it is able to follow their movement. Like the water vehicle, it carries drone to perform a searching task and exchange of information with the regional control center when it needs any equipment supply or assistance.

5) Rescue Copter: The objective of rescue copter is to search victims by utilizing long-range and high-resolution cameras and to carry compulsory materials such as pure water, foods and first aid box for the victims. Hence, it has a versatile capability that allows to round patrol for a large area with a remarkable payload and ability to fly in difficult weather and geographical conditions. It is, therefore, able to visit over the isolated remote villages that are not accessible by other vehicles. The operation of rescue copter is directly controlled by the regional control center, which communicates information to all the relevant teams in the case of critical emergency support such as sending victims to a hospital.

6) Regional Control Center (RCC): The RCC acts as a central point of all teams in a given region, which is a subset of the overall flood-affected area. The assignment of the RCC is to acquire rapid update of rescuing activities from all the teams in the corresponding region and supply any required assistance. Another task of the RCC is to control the rescue copter and also maintain

contact with the control center in order to exchange information about the flood situation and collect necessary equipment, medicals, and tools from the control center.

7) Control Center (CC): In our proposed CP-AGCM for the FRS, there exists only one CC, which acts as the head of the rescue mission and has ultimate authority over all the units. The CC controller has significant experience with regard to the flood situation. Its main role is to receive information from various RCCs and, according to the information, will provide direction, advice, relief supplies and equipment to the rescue teams. The central ministries, media, and various organizations retrieve updates from the CC.

3.2.2 Network Architecture of the Proposed Model

A key point of the thesis is on the utilization of TVWS to assist SAR actions by bridging the missing inter-team communications between the local and regional networks. In the established architecture, Wireless Local Communication (WLC), Wireless Regional Communication (WRC) based on TVWS and Wide Area Network (WAN) are designed based on LTE. Figure 3.2 depicts the proposed network architecture of the CP-AGCM. It is a three-tier architecture where the first tier is engaged to information acquisition, the second tier is engaged to data forwarding and the team maintains and the third tier is engaged in information processing for discovering the optimum solution as well as provide the basic need.

In this architecture, each team consists of HRs, drone and Water Vehicle/Land Vehicle (WV/LV). Usually, each rescuer collects or generates data about victims from the flood-affected area, which is transmitted to WV or LV by developing a WLC. Hence, the data collection is proceeded by two types of communication, i.e., Intra-team and inter-team communication. The searching actions are directed through rescue teams and rescue copter that can be seen in Figure 3.2. As noted before, the second tier is involved in data acquisition from teams and forwards them to the upper level. In this case, the WR/LR connects to the remote base station RCC and creates a WRC. The RCC receives data from different teams, thereafter, process and store this data. The saved data then can be further exploited by the teams and rescue copter. Moreover, following this information, the RCC gives direction to the teams in his region and also supply rescue copter for any emergency situation.

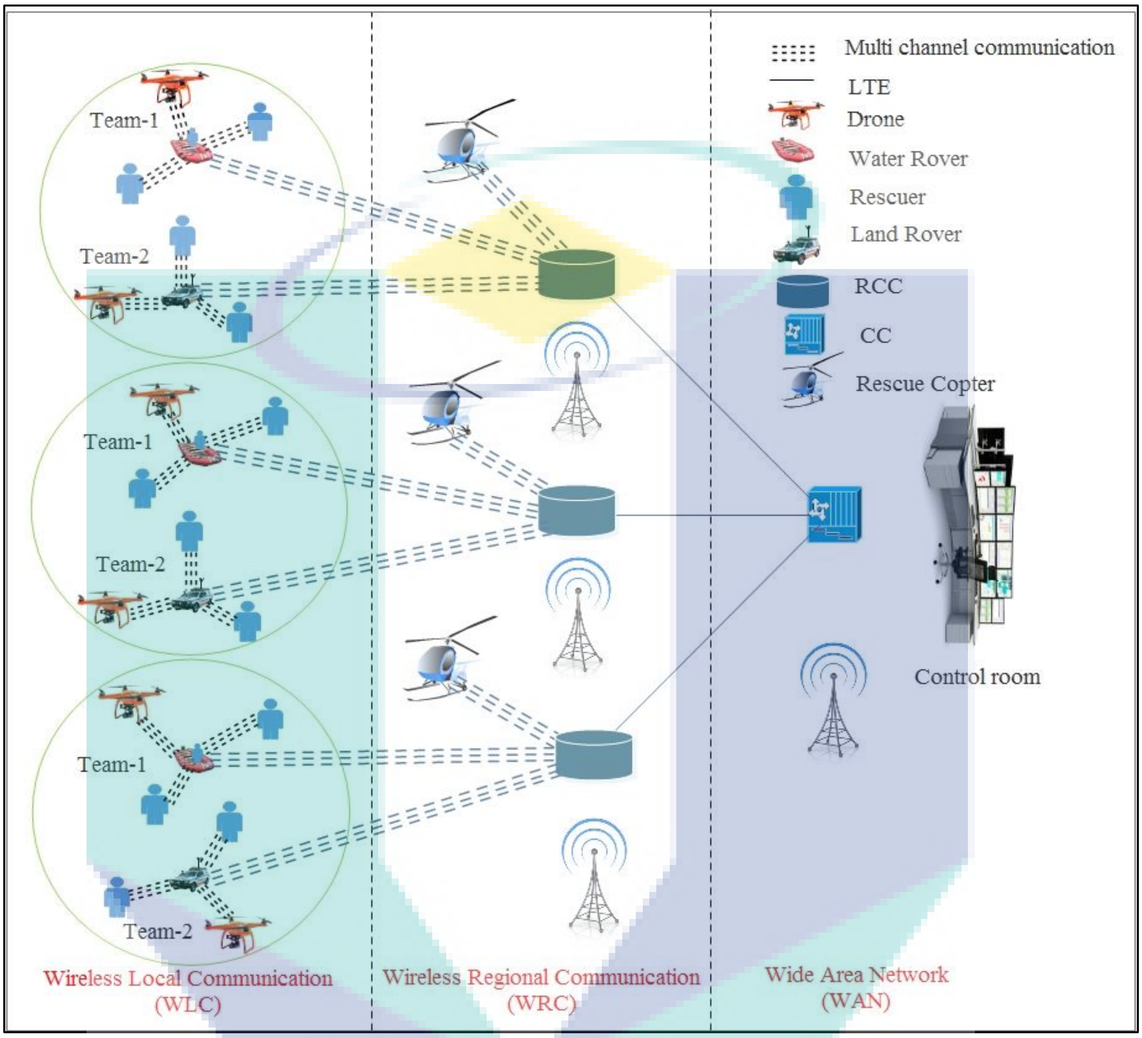


Figure 3.2 Overview of CP-AGCM for flood SAR operation.

The data aggregator, employed through the RCC agents, connects to the CC and establishes WAN. There are many possible communication technologies to create a WAN, for instance, through wireless technology (licensed spectrum) or wired access (fiber-optics, cable). In this case, wireless technology LTE is a suitable candidate to build a WAN. As mention before, the third tier in this network architecture is engaged in data processing, finding optimum solutions for the rescuers and obtaining feedback from the rescuers. After receiving this data from RCC, the CC process the requisite data and store them in a database, after discovering an optimum solution. Thereafter, periodically, it computes the best solution for one or more components as noted before. After that, these solutions are sent to the rescuers via RCC to facilitate the execution of

SAR procedures in the most efficient manner. Information is shared within a team through the LV/WV and local wireless connection. Each team can then exchange information with one another through the LV/WV and RCC. Both Intra-Team and Inter-Team communications can help to collect information efficiently in the FRS. The objective of the second feature is to forward the collected information to the upper levels of RCC and CC in order to store the information. This task can be accomplished by interconnecting the LV/WV, RCC, and CC. The stored information can then be further utilized by the teams and rescue copters so that an efficient victims searching mechanism can be designed. The objective of the third feature is to rescue the victims by exploiting the first two features and supply them with the essential first aid kit. The HRs and LV/WV provide support to achieve this goal. The collaborative efforts of all these network components can significantly improve the performance of SAR activities, to be discussed in Section IV.

3.2.3 Implemented Technology for CP-AGCM: Justification for TVWS

Hence, our effort to evaluate this significant characteristic and choose the appropriate technology for network communication in the flood scenarios. Hence mentioned some attractive features of TV white space that help to choose this technology.

Propagation characteristic: TVWS offers superior signal propagation characteristics and with minimal equipment can reach users in remote and rugged locations for search and rescue activities. The spectrum (UHF/VHF frequency band) of TV white space those frequencies that easily penetrate precipitation and bad weather areas which is very common in flood scenarios.

Penetration capability: Penetration is the magnificent feature of TV white space. In a typical home, a WiFi signal can penetrate up to two walls. At the same power, a TV white space signal can penetrate three-fold than WiFi signal and obstacles, enabling whole-home media distribution. This will simplify and enrich local area networking opportunities.

Better coverage: TV White Space technology could cover an area of about 10 kilometers in diameter (100 times the distance). While a conventional Wi-Fi router has a comparatively limited range, across 100 meters under appropriate conditions, and could be obstructed by walls or any other environmental barriers. This development technology is known as Super Wi-Fi considering its excellent range and capability to penetrate physical barriers such as buildings, trees, and rough terrains.

Non-Line-of-Sight (NLOS) Performance: Microwave links require line-of-sight (LOS) among the points to be connected. In regions with robust or forested landscapes, the tall towers essential to provide this line-of-sight link make microwave a costly and unfeasible solution. The TV White Space technology offers a reliable alternative to microwave by utilizing the lower-frequency UHF signals which can penetrate barriers and cover an uneven surface without requiring additional infrastructure.

License-exempt: TV white space is a license-free technology and the ability to being quickly deployed with minimal infrastructure and hence can be facilitated flood rescue activities by resuming the communication in a short time. Hence can be facilitated flood rescue activities by resuming the communication in a short time.

Inexpensive: The more interesting benefit of White space technology is the ability to roll out cheap, reliable broadband access to the disconnected disaster terrains where traditional networks cannot be easily deployed.

Real-time information: In emergency situations, the TV white spaces could be utilized to provide additional services to enhance public safety communications over licensed networks. As an example, rescue attempts can be increased by setting remote video cameras in a disaster place to relay images towards a command center; or utilizing portable devices to supply real-time video conference and surveillance, point of view control information. From this abode discussion, TVWS technology is considered the ideal candidate to enable the deployment for communication in the flood scenarios due to its attractive characteristics.

The main drawback of the TV White space is the feasible unavailability of the functional spectrum because of occupancy by incumbents. To cater this situation, to assign specific channels in the TVWS spectrum like high priority channels (HPCs) is a good solution. The HPCs can be leased for a limited time only by interested CR operators for exclusive temporary usage by paying a small license fee to the geo-location database provider. Table 3.1 summarizes the comparison of existing wireless technologies by addressing the important characteristics. Since the flood-affected area is in terms of km scale, high transmission coverage is therefore required. In this context, TV white space is suitable candidates due to his high coverage, whereas the others are less preferable. It has reasonable data rate that can support real-time pictures and videos. This is a license-free technology and also has some excellent features which are shown in the table.

Table 3.1 Significant features of communication technologies relevant to SAR network

Technology	Data Rate	Frequency	Coverage	Licensed/ Unlicensed	Benefits	Limitations
LTE	300Mbps	900MHz	30km	Licensed	Higher data rate; high throughput; low latency	Need complicated hardware; more power consumption; more expensive
4G	4-12 Mbps	700-2500MHz	10km	Licensed	High data rate	Complex infrastructure , expensive
Satellite Communication	1-10 Mbps	1-40GHz	28100-36000 km	Licensed	Long-range	Low data rate
WiMAX	Up to 75Mbps	2.5Hz, 3.5GHz,5.8 GHz	1-50km (NLOS) 10-50km (LOS)	Both	Long-range, high data rate	Not widespread, Cannot penetrate obstacle
TVWS	Downlink: 1.5Mbps, uplink: 384Kbps	54-72 MHz 174-216 MHz	30-100km	Unlicensed	Long range, High propagation feature, penetrate obstacle	potential interference by license band
Mobile Ad hoc	250 Mbps	30 MHz– 5 GHz	5 km	Licensed	Medium deployment time and maintenance cost,	High installation cost, low latency

3.3 Collaborative Search Algorithm for Multi-Victim

Among the existing search algorithms Probabilistic Search Algorithms (PSAs) are the most popular algorithms, which were utilized in many practical SAR operations, However, most of these algorithms are noncollaborative and they integrate a Probability Distribution Map (PDM), which contains the probability values of the presence of a target(s) at various locations within the overall search area. In PSA, the starting cell of a SAR operation for a team could be determined based on several parameters including Point Last Seen (PLS) and Last Known Position (LKP) or could be determined randomly. If the target is not discovered in the current cell, the next visiting cell is selected based on the highest probability in the PDM within the 1-level neighborhood.

Generally, PSAs utilize local information to find the next visiting cell and hence, it is unable to exploit collaborative efforts of multiple teams. Therefore, in PSAs, multi-team revisits of a single cell are highly likely. To overcome this problem, a collaborative searching approach is proposed in (Rahman et al., 2018b), called Collab-SAR (Collaborative Search & Rescue), where PDM update is performed globally for all the teams and cell visiting information is also accumulated globally. In (Rahman et al., 2018b) the authors also proposed a new searching algorithm, called Expanding Neighborhood Search Algorithm (ENSA). The ENSA is an enhancement over the PSA, where the former performs searching up to α-level neighborhood instead of 1-level neighborhood like the latter to select the next cell, where $\alpha \in Z^{+}$. An inherent characteristic of ENSA is given by an expansive search function, starting from 1-level neighborhood and reaching until α-level neighborhood with an objective of discovering the most probable cell that may contain a Victim Point (VP). Therefore, the optimum value of α plays an important role in attaining improved performance in ENSA.

However, ENSA cannot be directly applied to the scenario that is taken into account in this paper since it assumes only one victim point and all the teams involved in a SAR operation perform a collaborative effort to find the target point. It is so because the ENSA is solely designed for the Avalanche Search & Rescue operations, where generally an avalanche occurs at a particular point. Conversely, the scenario that is considered in this paper contains multiple victims points, which are distributed over a given area. Therefore, an enhancement over ENSA is performed to incorporate multi victim scenario and hence, called ENSA for Multi-Victim or ENSA-MV.

Analogous to ENSA the PDM is utilized to find the next cell and it is updated globally by exploiting the advantages of the collaborative rescue effort. Dissimilar to ENSA, the searching process will continue until all the victims are discovered. In ENSA-MV, the next cell is selected through searching via 1-level neighborhood until reaching α-level neighborhood and the most probable cell is selected within the search region as the next visiting cell. The proposed searching approach is elaborated in Algorithm 1. As could be observed from the algorithm is that the process of searching starts by selecting a cell based on the Point Last Seen.

Once a cell visiting is complete the next cell is selected within the α-level neighborhood. For that, two conditions are taken into account, namely, i) the most probable cell where the victim could be found based on the PDM and ii) status of the visit is "false" according to the accumulated (globally or locally) cell visiting information. If both the conditions are satisfied, the next visiting cell is found. Conversely, which may occur only if all the cells are already visited, the next visiting cell is selected arbitrarily within an α-level neighborhood. Before leaving the current cell, visiting status of this cell is updated in a global table and its probability is revised based on the Recursive Bayesian Estimator (RBE) (Rahman et al., 2018a). This procedure continues until all the victims, β are discovered as demonstrated in Algorithm 1.

Algorithm 1: Collaborative search algorithm

REMARK: x, x', y and y' are x-coordinator, new x-coordinator, y-coordinator, new y-coordinator respectively. β is the number of victim(s).

Constant: α, β, $x' \leftarrow -1$, $y' \leftarrow -1$

Input parameter: x, y, $\mu \leftarrow 0$

Assert($\alpha > 0$)

Select $and\ y'$ based on Point Last Seen

Look for the victim in the current cell

If Victim discovered then

    $\beta -= 1$

End if

```
Update the probability of the cell based on the Recursive Bayesian Estimator
x ← x′
y ← y′
While β ≥ 1 do
        For δ ←1 to α do
                For j ← δ to δ do
                        temp_x ←x + δ
                        temp_y ← y + j
                        if temp_x or temp_y are outside the given area then continue
                        else
                                if probability of finding victim in the selected cell is
                                greater than μ and the cell is not visited before then
                                        Assign temp_x and temp_y to x′ and y′, respetively
                                        Update μ value with the new probability
                                end if
                        end if
                end for
                for j ← − δ to δ do
                        temp_x ← x − δ
                        temp_y ← y − j
                        if temp_x or temp_y are outside the given area then continue
                        else
                                if probability of finding victim in the selected cell is
                                greater than μ and the cell is not visited before then
                                        Assign temp_x and temp_y to x′ and y′, respectively
                                        Update μ value with the new probability
                                end if
```

```
                    end if
            end for
            for j ← − δ + 1 to δ − 1 do
                    temp_x ← x + j
                    temp_y ← y + δ
                    if temp_x or temp_y are outside the given area then continue
                    else
                            if probability of finding victim in the selected cell is
                            greater than μ and the cell is not visited before then
                                    Assign temp_x and temp_y to x′ and y′, respectively
                                    Update μ value with the new probability
                            end if
                    end if
            end for
            for j ← − δ + 1 to δ − 1 do
                    temp_x ← x + j
                    _y ← y − δ
                    if temp_x or temp_y are outside the given area then continue
                    else
                            if the probability of finding victim in the selected cell is
                            greater than μ and the cell is not visited before then
                                    Assign temp_x and temp_y to x′ and y′, respectively
                                    Update μ value with the new probability
                            end if
                    end if
            end for
      end for
```

```
        if x′, y′ ≠ - 1 then return;
        else
            Select location at random: location ∈ α-level neighborhood
        end if
        Look for the victim in the selected cell
        If victim discovered then
            β- = 1
        end if
        Update the probability of the cell based on the Recursive Bayesion Estimator
    end while
```

3.3.1 Variants of ENSA-MV

Similar to ENSA, three variants of ENSA-MV are introduced in this thesis based on the PDM updating mechanism, namely: i) No PDM Update (NPU), ii) Local PDM Update (LPU), and iii) Global PDM Update (GPU). Here, in NPU, as the name suggests, no PDM update occurs and it is memoryless. Hence, among the three variants of the ENSA-MV, it is the simplest one in terms of implementation. In NPU cases, it is most likely that a single grid may experience revisiting multiple times. On the other hand, the PDM updates are performed locally within a team in case of LPU. Similar to NPU, LPU is non-collaborative and hence, the PDM update information is never announced outside the team. Again, to prevent revisiting a cell, it accumulates visiting information per iteration. Once a cell visiting is complete, its probability is revised employing the RBE as mentioned earlier in this Section. Next, to reduce the searching time of the SAR activities, GPU supports both collaboration and cooperation. Here, the updated estimation of the probability of finding victims—which is calculated after visiting that cell employing the RBE—is announced globally to maintain consistency of the changing global probability map of the disaster area. In addition, cell visiting information is also accumulated globally, which is later employed in selecting a subsequent cell to visit, aiming at minimizing search duplication and overlapping.

3.4 Conclusion

This chapter illustrates the proposed collaborative network model for SAR operation named CP-AGCM in details to reduce fatalities after flood disasters. The proposed model is validated by MATLAB simulation. In this simulation, the area is considered as 100 km and the entire area is covered with dry land area, water and muddy covered area, and critical area. In this scenario, the proposed model is applied with three domain SAR activities and is validated by this model. The network architecture is drawn of these scenario and numerous components of these SAR operations are explained in this chapter. Some key points that must be considered in such scenarios are also described in this chapter. The TV white space technology is used in this model to an established communication network by CPS. There are some attractive characteristics of TV white space networks that are inspired to choose this technology which is mentioned here. Finally, the effectiveness of the network is validated by NS-2. In chapter 4 is described the performance investigation of the CP-AGCM and network effectiveness in detail.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This study describes a collaborative cyber-enabled mission critical system where numerous rescue agents and victims communicate with each other in the flood-affected area. The resilient collaborative communication between the rescue agents can play a significant role to increase the overall performance of rescue activities. The concept of cyber-physical system (CPS) could be utilized in emergency rescue communication, as increasing the efficiency of existing technology because of the uplifting demand of applications for disaster-affected areas. In order to do the non-collaborative communication infrastructure are provides as a prominent solution. However, this solution is not flexible due to a lack of reliable communication. Moreover, collaboration among the rescue agents and victims can be an important issue during search and rescue operations. In this chapter, a comprehensive performance investigation on CP-AGCM has been carried out in order to address the issue. (i) The effectiveness of collaborative CP-AGCM model, (ii) evaluate the performance of collaborative searching algorithm and (iii) the performance of the system and network has been investigated and some open research issues are addressed.

4.2 Validation of the Proposed Model

In this section, we validate the effectiveness of the proposed collaborative model through simulated SAR activities, which incorporate a search for and provision of aid to the people in suffering or imminent danger.

The scenario of the model: Figure. 4.1 depicts the scenario of a flood-affected region where the area is 100 km. The whole area is encircled by all the Land Covered

Area (LCA), Water Covered Area (WCA) and Critical Area (CA). Here, LCA is a dry or muddy area where water did not reach, however, surrounding can be submerged by water. Similarly, WCA is a submerged area, which is a major part of the scenario. And the CA is a jungle area. We carry out experiments in order to validate the effectiveness of our proposal considering this scenario.

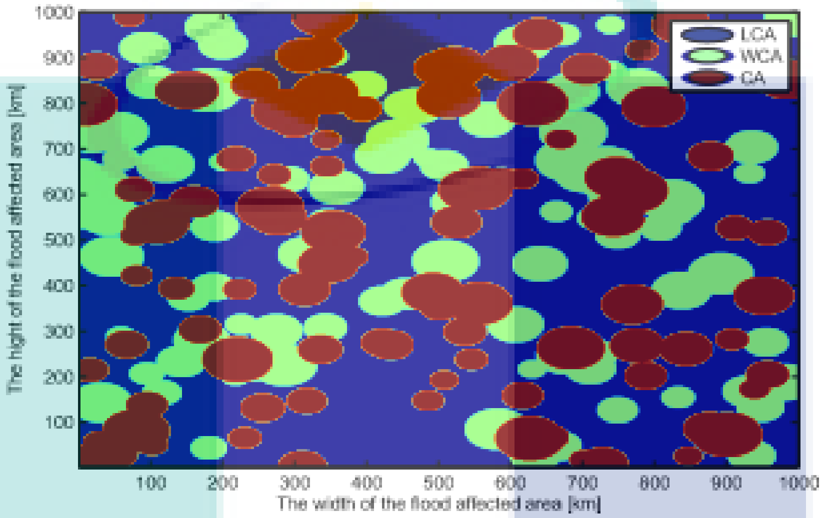


Figure 4.1 The affected area covered by LCA, WCA, and CA during the flood.

Validation: For the purpose of benchmarking and comparison, we categorize the air-ground SAR model into three types: i) one dimensional SAR (1D-SAR), i.e., if the rescuers are able to search only the LCA, referred to as the traditional SAR; ii) two dimensional SAR (2D-SAR), i.e., if the rescuers are able to search both the LCA and WCA; iii) three dimensional SAR (3DSAR), i.e., if the rescuers are able to search not only the LCA and WCA but also the CA, which is an area where the only drone is capable to reach for performing the search activities. The proposed collaborative network is designed to perform the air-ground SAR.

In Figure 4.2, we measure the performance of 1D-SAR, 2DSAR, and 3D-SAR with respect to the number of rescued victims from the number of victims in the scenario. The simulation set is as follows: the area is 100 km; the number of victims set ϑ = [10, 20, 30, 40, 50, 60, 70, 80, 90, 100] is randomly placed in the flood-affected area; the number of WCA and CA are 100, which are randomly placed inside the network area; the depths δ of the WCA and CA are chosen randomly from 200 m to 500

m. It can be observed that, by using the 1D-SAR, we are not able to rescue the victims who are in the WCA and CA regions, since they are not searchable by the 1D-SAR enabled rescuers. By using the 2D-SAR, we are able to rescue more than that using the 1D-SAR but not the victims who are in the CA region. By exploiting the 3DSAR, we are able to rescue more victims compared to 2Dand 1D-SAR. In this case, the 3D-SAR seems to outperform the others because all the disaster area can be accessed either by the land rover, water rover, LRMAV or SRUAV.

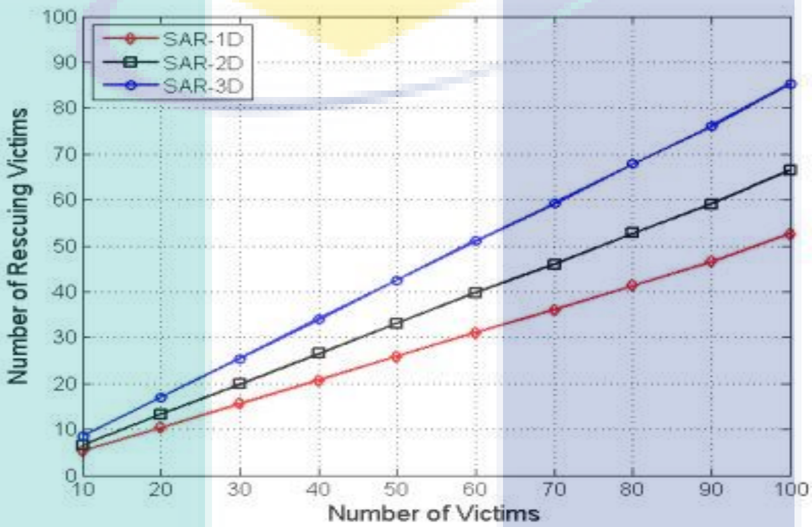


Figure 4.2 The efficiency of the rescuing activity by 1-D, 2-D and 3-D SAR.

If the number of WCA and CA increase, the flood-affected area will be more severe. In this case, the performances of the 1D-SAR and 2D-SAR degrade more compared to the 3D-SAR, as depicted in Figure 4.3. In this experiment, the simulation setup is mostly similar to that in Figure 4.2 with the following minor differences. The number of victims in the scenario is 100 and the sets of an average number of WCA and CA are both given by [10, 20, 30, 40, 50, 60, 70, 80, 90, 100]. We notice that, by increasing the number of WCA and CA for a given area, the LCA is effectively reduced, and as a result, the number of victims is less in the LCA. In this case, the 1D-SAR is only able to rescue fewer victims compared to the 2D- and 3D-SAR.

The flood-affected area is also more severe if the average depths δ of WCA and CA increase. In this case, by following a similar line of reasoning to that in Figure 4.2, the performances of the 1D-SAR and 2D-SAR deteriorate more than that of the 3D-SAR, as shown in Fig. 4.4.

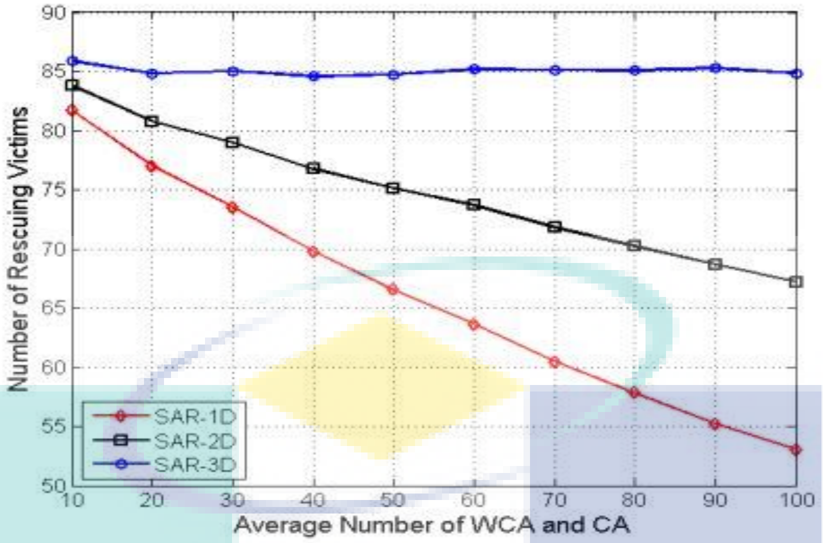


Figure 4.3 The effectiveness of the rescue mission varies with the number of WCA and CA.

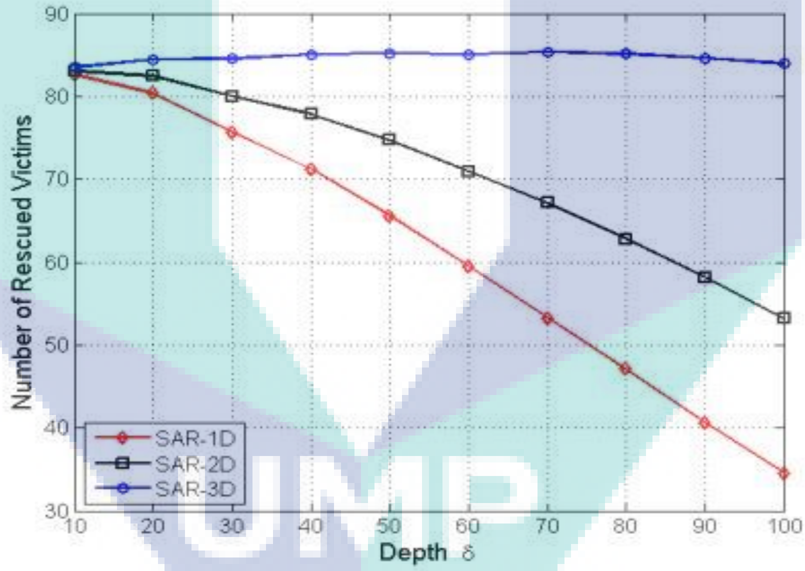


Figure 4.4 The effectiveness of the rescue mission varies with the number of WCA and CA.

These results demonstrate that the proposed network model offers promising characteristics and potential to improve the effectiveness of the SAR activities in the flood-affected area.

4.3 Performance Evaluation of Collaborative Search Algorithm

This section discusses the system model that is taken into account during numerical simulations and other relevant algorithms that are compared with the proposed algorithm.

4.3.1 System Model

For our numerical simulation, a Euclidean area of 10 km × 10 km is considered in this work, which is divided into an equal fixed cell size 0:1 km × 0:1 km later. The PDM of this area is generated considering two aspects: i) all the cells must not be assigned identical probability value and ii) for maintaining continuity between the adjacent cells, a certain degree of relationship must be maintained between them with no drastic difference in terms of probability values.

In our simulation, the value of VPs is considered randomly from 1 to 10. Again, to introduce randomization in the selection process, a random variable ρ is generated according to Eq. 4.1, which draws a value from [0; τ]; τ refers to the highest probability received in the PDM.

$$\rho = \frac{(\frac{1}{1+e^{-5.5-\vartheta}} - 0.5) \times \tau}{0.4959} \quad . \qquad 4.1$$

Here, $\frac{1}{1+e^{-5.5-\vartheta}}$ is obtained from a modified Sigmoid Function where ϑ is a random variable with uniformly distribution that draws value from 0 to 1.

One of noteworthy properties of ρ is that it has a tendency towards τ value. Therefore the cells with higher probability values in the PDM have higher likelihoods of selecting as VPs. A certain cell is selected as a VP if its probability in the PDM is within a tolerance range of $\pm 10^{-6}$ to the value of ρ. Again, to eliminate selecting a certain cell every time for a certain ρ value, the coordinate value of x and y are chosen randomly. This procedure repeats until all the VPs are selected.

In the simulation, a number of teams are varied that are deployed to find the VPs, ranging from 1 to 20. Two constraints are imposed during the deployment process, namely i) only one team can visit a single cell at a certain time and ii) no concurrent cell visiting by more than one team is allowed. Moreover, when a team is utilizing the ENSA-MV, it can choose the next cell within the 4-level neighborhood since α is suggested as 4 in (Rahman et al., 2018b) to attain improved performance.

The proposed algorithm's performance will be measured by exploiting two metrics: i) Average Number of Visited Cells and ii) Time Spend [hr]. The time spend to discover all the victims is calculated as:

$$\mu = \mu_p + \mu_c + \mu_t \qquad 4.2$$

Here, the parameter μ_p is the preparation time, i.e., the time requires in packing before shifting to the next cell and is considered as a constant value in our simulation. Conversely, μ_c varies and denotes the time requires to reach the next cell from the current cell in traveling, which mainly depends on the distance between the current cell and the next cell and the movement speed, ϑ_c. Again, μ_c denotes the searching time of cell by a team, which can be calculated as $\mu_c = {}^{\sigma_c}/_{\vartheta_v}$ where σ_c and ϑ_v denote the area of the cell and the average time taken for searching that cell, respectively. In the simulation, all the aforementioned parameters such as ϑ_v, τ_p and ϑ_c are assigned 10 m/s, 180 s and 1:5 m/s, respectively.

4.3.2 Other Considered algorithm

In order to measure the proposed searching algorithm's performance, it is compared with the other two relevant prominent algorithms: i) Random-Search-Algorithm (RSA) and ii) Probabilistic-Search-Algorithm (PSA). In RSA, the next cell selection is performed randomly within 1-level neighborhood. Therefore, the PDM is not required for this algorithm and hence, it is simple in terms of implementation compared to other algorithms. For the comparison, three variants of RSA are proposed, such as: i) No-Memory (NM), ii) Local-Memory (LM), and iii) Global-Memory (GM). Here, NM does not take the previous cell visiting knowledge into account. Therefore, it is highly likely that a same cell can be visited repeatedly. In case of LM, the information of the self visited cell is accumulated and utilized in the next cell section process. Conversely, GM collects all information of a cell that is visited by the previous teams (i.e., a collaborative approach) and employs it to select the next cell.

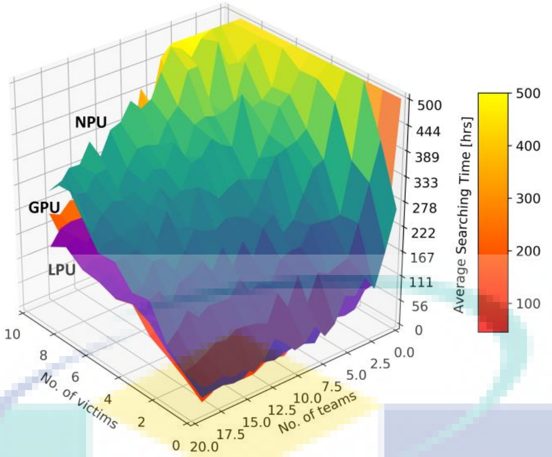
Again, similar to ENSA-MV, PSA selects the next cell exploiting a probabilistic algorithm. The primary difference between them is: the next cell selection within the first-level neighborhood is based on latter algorithm, and it is chosen within α-level neighborhood in the former algorithm. Alike the proposed algorithm, three variants of this algorithm are proposed which are discussed in detail in section 3.4.1.

4.3.3 Findings and Discussions

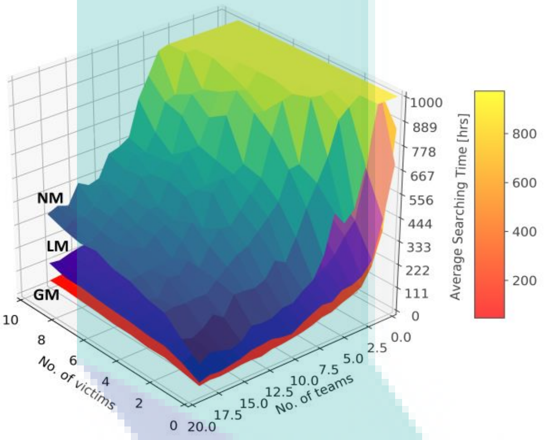
The figures, 4.5(a), 4.5(b) and 4.5(c) exhibit the time spend [hr] of by different teams in discovering various numbers of VPs for all three compared SAR algorithms, namely RSA, PSA, and ENSA-MV, respectively. As could be observed from the figure is that when a number of teams are more and a number of VPs are few, lower time is spent in discovering all the victims. In oppose to that, it increases with increasing number of VPs and decreasing number of teams for all compared algorithms.

The RSA shows the lowest performance compared to the other two algorithms due to selecting the next visiting cell randomly. Again, NM spends the highest amount of time in discovering the VPs among the three variants of RSA. On the other hand, LM demonstrates considerably better performance over NM as it accumulates cell visiting information locally and utilizes it in the next cell selection. Thus, it eliminates likelihood of revisiting a cell by the same team. However, a cell still may experience revisit by one or multiple team(s) due to the absence of collaboration among the teams. GM resolves this issue by accumulating cell visiting information globally and hence, demonstrates the best performance among the three variants. Average spend time by 20 teams for discovering 10 VPs for NM, LM, and GM are 415:12, 380:1, and 295:67, respectively.

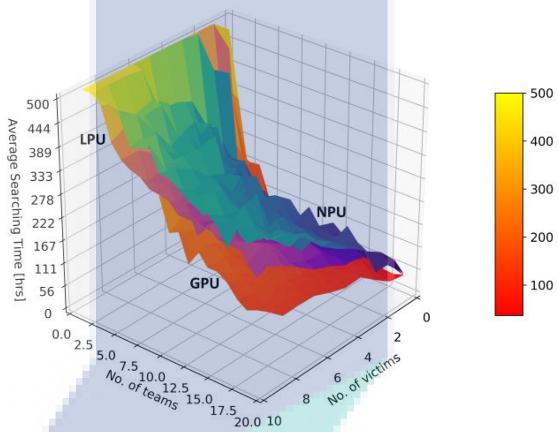
In compare to ENSA, PSA exhibits better performance in discovering VPs within a short period of time. It happens due to utilizing the PDM in discovering the next visiting cell. The PDM is also utilized in our proposed algorithm, ENSA-MV. However, it demonstrates superior performance over all the compared algorithms due to its new searching strategy. In ENSA-VM, the most probable cell within the α-level neighborhood is chosen as the next visiting cell instead of 1-level neighborhood like PSA.



(a) Time spend [hr] for the RSA with respect to various number of victims and various number of teams.



(b) Time spend [hr] for the PSA with respect to various number of victims and various number of teams.

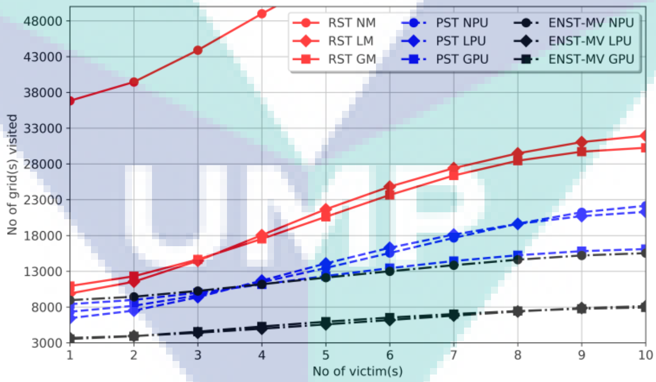


(c) Time spend [hr] for the compared SAR algorithms.

Figure 4.5 Time [hr] for the compared SAR algorithms.

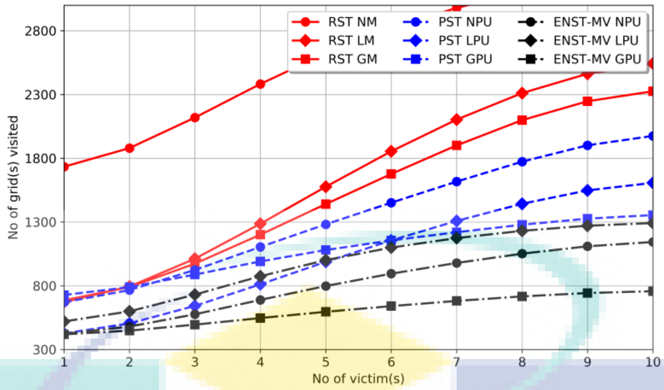
Again, for both PSA and ENSA-MV, three variants are proposed (see Section 3.4.1 and Section 4.4.2), where NPU and LPU are non-collaborative approaches and GPU is collaborative approach. Among the three variants, NPU receives the poorest performance due to ignoring the PDM update and cell visiting information during the next cell selection process. This approach spends around 326:46 hours and 267:7 hours to discover 10 VPs for 20 teams using PSA and ENSA-MV approaches, respectively. Even LPU demonstrates superior performance over NPU due to updating the PDM locally and utilizing local cell visiting knowledge during the next cell selection. In this case, 20 teams spend around 265:59 hours for PSA and 153 for ENSA-MV in discovering 10 VPs. Again, since GPU utilizes the collaborative approach, it outperforms the other two variants. In GPU, the PDM is updated globally and cell visiting knowledge is also accumulated globally, which are later utilized for selecting the next cell. It spends around 228:31 hours and 121:06 hours for 20 teams to discover 10 VPs for PSA and ENSA-MV approaches, respectively.

In figures 4.6(a), 4.6(b) and 4.6(c) average number of visited cells for all the compared algorithms are exhibited with respect to various number of victims for 1, 10, and 20 teams, respectively. As could be observed from the figures is that the average number of visited cells follow the similar trend which is observed for average searching time. In other words, if three algorithms are ordered based on their performance, RSA exhibits the poorest performance, PSA demonstrates some improvements over RSA, but it fails to overpower ENSA-MV. The reasons are similar to those which are mentioned previously for time spend metric. Again, among the several variants of the compared algorithms, the one which utilizes the collaborative approach, i.e., GPU, outperforms other two non-collaborative approaches, namely NPU and LPU due to the same reasons which are elaborated before for average searching time.

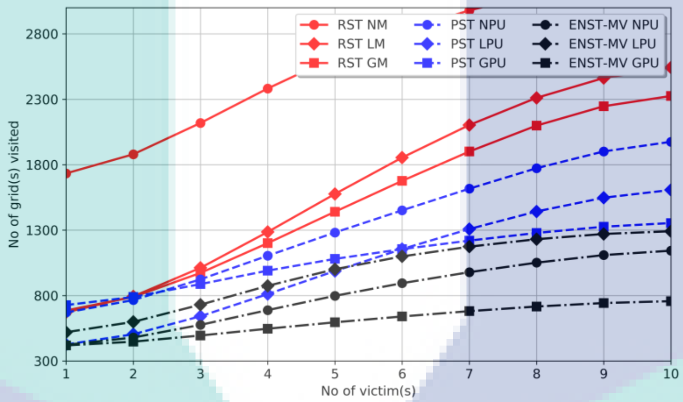


(a) Average number of visited cells with respect to number of victim(s) for 1 team.

Figure 4.6 Average number of visited cells for the compared SAR algorithms.



(b) Average number of visited cells with respect to number of victim(s) for 10 teams.



(c) Average number of visited cells with respect to number of victim(s) for 20 teams.

Figure 4.7 Continued.

4.4 Performance Evaluation of CP-AGCM Network

This section evaluates the performance of the proposed collaborative CP-AGCM network model through numerical simulation. NS-2 is widely preferred simulator among the networking research community, so it has been used for the simulation experiments. The first and foremost task is to design the scenario which will resemble the flood-affected area, as we discussed in Figure 3.2. Then the network performance metrics will be considered which assists to measure the performance of CP-AGCM network model. Finally, two experiments will be conducted in order to show the effectiveness of the utilization of TVWS and the consistency of the proposed network model. All the aforesaid aspects will be discussed in the following sub-sections:

4.4.1 Network Scenarios

The considered network size is 10^2 km, where the entire area is divided into 1000 x 1000 grids. Each grid is considered as 10^2 m, which can be easily searched by a rescuer. A Control Center (CC) is placed in the center of the area, where all the rescuers can send their searching information into the server in a multi-hop manner. Three access points of the three Regional Control Centers (RCC) are placed in the network in such a way where APs can directly communicate to the server. There are three teams are placed inside an RCC. The rescuer can communicate with others through the AP of the team such as water vehicle and/or land vehicle. Moreover, the rescuers, drones, rescue copter, water, and land vehicles are mobile so that they can move from one region to another. However, the RCC and CC remain static.

4.4.2 Simulation Setup

According to the random *way point* model CUs move in a square area, whose size has been set such as it fits with a node density equal to 200 nodes/Km^2. The transmission range of the CUs has been set to 120 m, the transmission standard is the IEEE 802.22 and the propagation model is the *Two-Ray Ground* one. In this simulation, the transmission range of primary user (PU) and the secondary user transmission range is periodically set at 300 m and 120 m, and channel frequency is set 2.4 GHz. The SUs are mobile and their transmission range is variable. The workload is modeled as Constant Bit Rate (CBR) data packets 1000 bytes along over User Datagram Protocol (UDP) connections, and each node generates one data flow toward a destination selected randomly. Accounting for the (Gupta & Kumar, 2000) bound, the throughput generated by each source has been set to $\frac{W}{10\sqrt{n}}$, where W is the link data throughput and n is the number of CUs in the network. The duration of each run is 1000s and the data traffic is active in the interval [60,1000] seconds. For each experiment, we performed five runs computing both the average value and the standard deviation for each metric: (i) Packet Delivery Ratio (PDR); (ii) delay (iii) routing overhead. The summary of the simulation parameters is shown in table 4.1.

Table 4.1 Simulation Parameters.

Parameters	Values
Propagation Model	Two-ray ground model
Area size	1000 m * 1000 m
Mobility model	Random way-point model
Data traffic model	CBR over UDP
Performance measuring metrics	PDR, delay and overhead
Routing protocol	D^2CRP
Simulation times	1000s
Number of channels	[1, 5, 10]
Minimum MN speed	2 m/s
Maximum MN speed	6 m/s
Minimum data rate	0.54 Mbps
Maximum data rate	2.7 Mbps
Each experiment run number	5

4.4.3 Experiments

Based on the above network scenario, we have conducted two experiments in order to measure the performance of the proposed model by exploiting TVWS technology. In the first experiment, we will show the effectiveness of TVWS in our considered scenario. The concept of TVWS as adopted from Cognitive Radio Networks (CRNs), where there are two users can be utilized the spectrums of the TVWS. One user is called Primary User (PU) who is the real user of the networks and another one is called the Secondary User (SU) who can use the spectrum while the PU is inactive. In the considered scenario, we assume that the PU will be always inactive as the flood-affected area is normally in the remote area. All the actors are considered as SUs here. Therefore, we assume that the TVWS spectrums are always available for the SUs and we can get the benefits of multi-channel in this context. We also considered a prominent routing protocol for CRNs in this simulation named as Dual Diversity Cognitive Ad-hoc Routing Protocol (D^2CARP) (Rahman et al., 2012).

In the first experiment, the results have been collected in three figures. Each picture corresponds to a performance metric with a variation of a number of channels and MN speed (i.e., the rescuers, drone and so on). In all the graphs, X-axis represents the number of mobility nodes (MN) and Y-axis indicates the value of the performance metric. The varying number of channels set is [2, 4, 6, 8] (Mobedi & Nejat, 2012). Simulation parameters are depicted in Table 4.1.

Figure 4.7 is depicted the simulation results for PDR by varying the number of channels and number of mobility node (MN). The first important observation that as the MN increases, the PDR decreases for all three number of channels. Therefore, the packet loss percentage will increase whenever the network is denser. Performance of the two channels is reducing regularly while the PDR is increasing in the case of 4, 6 and 8 channels. The second important observation is the superiority of increasing channels in terms of the packet delivery ratio over the lower number of channels. Lower number of channels achieves the lower packet delivery ratio and the higher packet loss percentage.

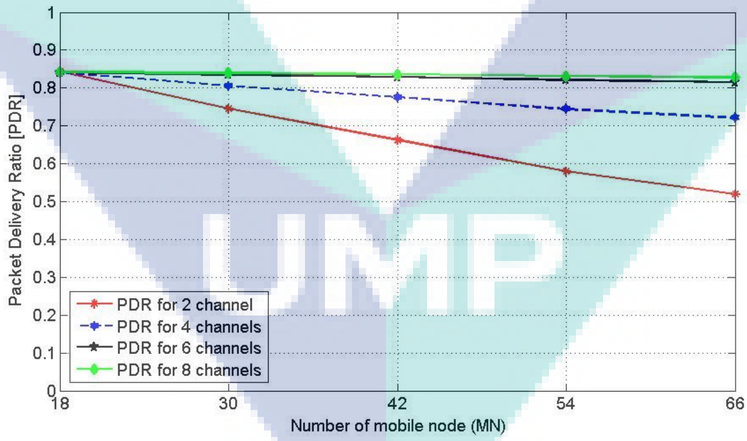


Figure 4.8 PDR vs MN performed on four different channels.

Figure 4.8 shows the variation of the delay time for 2, 4, 6 and 8 channels. The lower number of channels consistently shows the higher delay time. As less channel needs more time in route discovery, it produces more delay time, therefore the delay time for less channel is longer than more channels. From the above study on delay time, 8 channels have the shortest delay time as compared to 6, 4 and 2 channels, it means that the more channels have high reliability than the less channel.

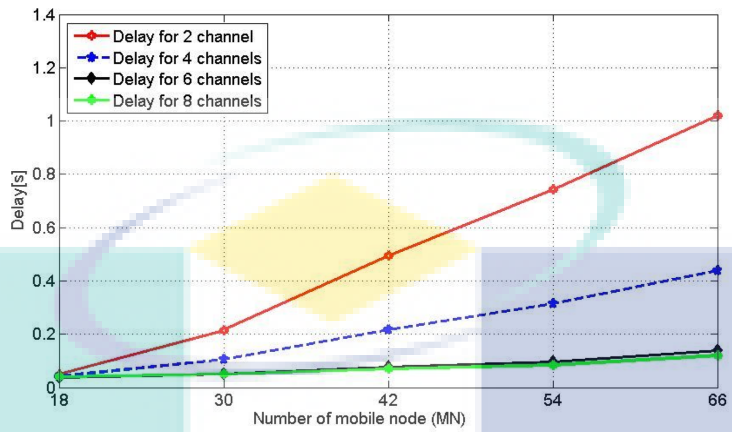


Figure 4.9 Delay vs MN performed on four different channels.

Figure 4.9 depicts the results for the routing overhead. As the node density increases, more nodes would be involved in sending the packets from source to the destination. Therefore, routing overhead also increases for all number of channels. Eight channels have the lowest overhead as compared to 6, 4 and 2 channels, it means that the number of channels increases, the overhead decreases, therefore more channels are better than fewer channels.

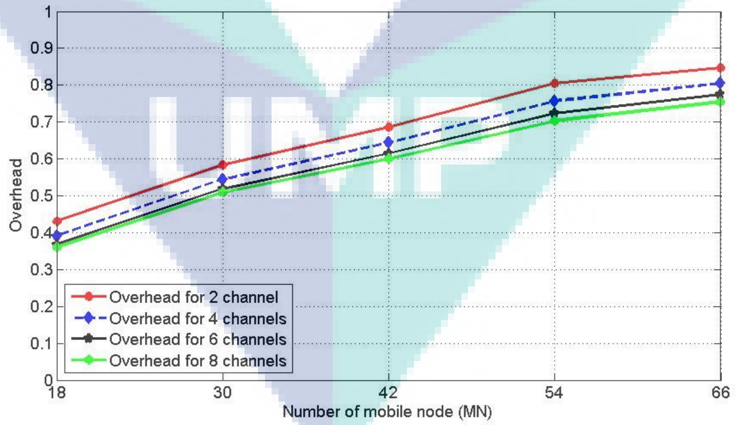


Figure 4.10 Overhead vs MN performed on four different channels.

On the other hand, we have analyzed the performance of the network by varying the speed of mobility nodes (MN speed) in the second experiment. The simulation set is similar like the first experiment, however, the differences: MN speed set is (1 m/s, 3 m/s, 5 m/s and 7 m/s).

Figure 4.10 shows the simulation results for PDR by varying the mobility node (MN) speed and number of mobility node (MN). The figure presents that as the MN increases, the PDR decreases for different node speeds. In the simulation process, the MN speed 1 m/s has the highest PDR as compared to 3 m/s, 5 m/s and 7 m/s even by escalating the number of MN. With the increase in MN speed, the PDR decreases. When the MN speed decreases, the PDR increases slightly.

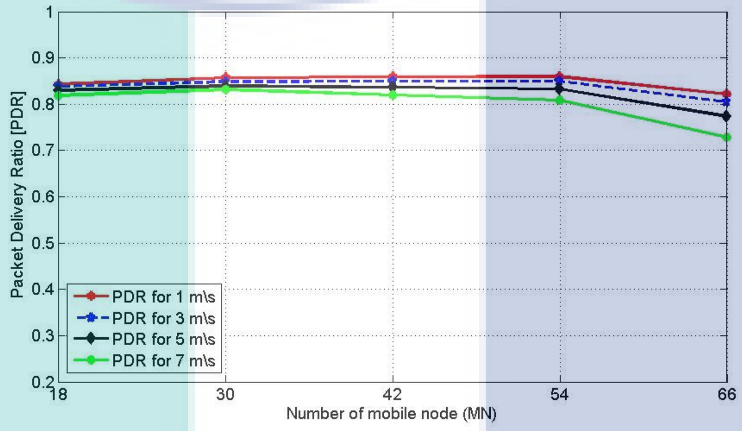


Figure 4.11 PDR vs MN performed on four different data rates.

Figure 4.11 depicts the simulation results for delay time with a variation in the MN speed and number of MN. As the number of nodes (MN) increases, the delay time

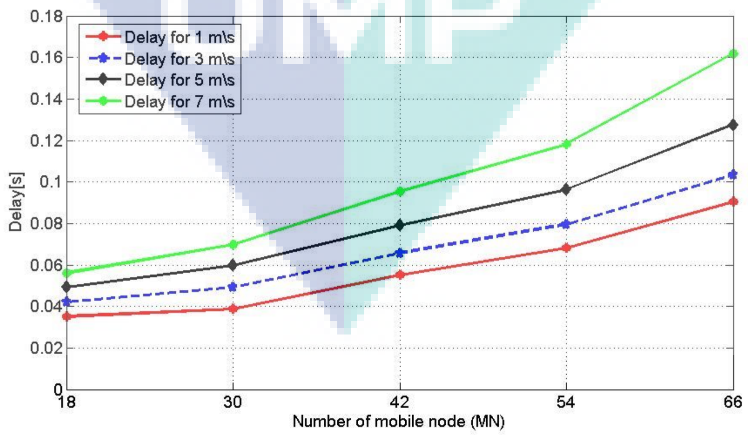


Figure 4.12 Delay vs MN performed on three different speeds.

also increases for all node speed. With the decrease in node speed, the delay time decreases.

Figure 4.12 presents the simulation results for routing overhead by differing the MN speed and number MN. As the MN increases, the overhead also increases periodically for all node speed. With the decrease in node speed, the routing overhead decrease.

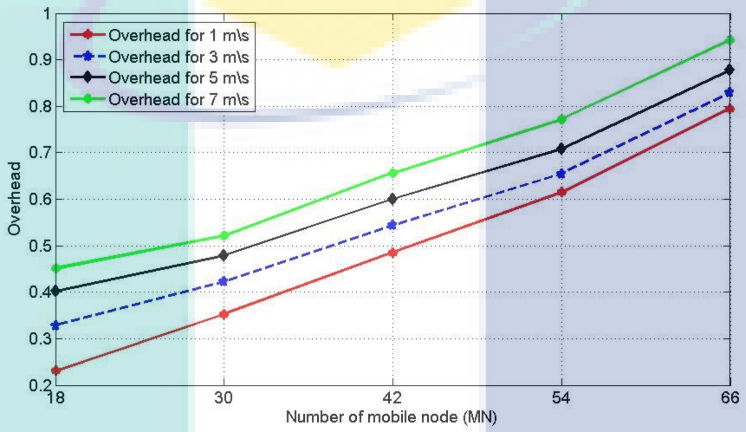


Figure 4.13 Overhead vs MN performed on three different speeds.

Based on the first experiment: with the increasing number of channels, the PDR increases, delay time and routing overhead decreases, therefore the performance of multi-channel is better than the single channel. Again, based on the second experiment: with the decrease in node (MN) speed, the PDR increases, delay time and routing overhead decreases, therefore node speed 1 m/s has high performance as compared to 3 m/s, 5 m/s, 7 m/s. However, overall performance is good, even high speed while we exploit multiple channels. Thus, it can be concluded that by exploiting TVWS, the performance of the network especially in disaster scenarios is significantly improved.

4.5 Conclusion

In this chapter, the validation of the proposed CP-AGCM model which exploits the TVWS spectrum as network backhaul links to support rapid and effective post-flood SAR activities is described. The proposed network model has been aimed to extend the ProSe for mission-critical data exchange, which includes acquisition of victim's information, transmission, and storage of the collected information, and development of the follow-up rescue activities. The capability of the proposed CP-AGCM system has been evaluated through numerical simulation. In simplicity, at first, the capability of the proposed model for SAR operation is explored through MATLAB simulation. This SAR operation is conducted by three domain i.e., 1D SAR, 2D SAR and 3D SAR with the number of rescued victims from the number of victims in the scenario. As well as the implementation of a global search algorithm exploiting the collaborative nature of the network agents in this model is also discussed. In the second phase, simulate the proposed network by NS-2 and evaluate the outcomes by considering the metrics of PDR, delay, and overhead. The performance has been evaluated with introducing the CP-AGCM by considering relevant network communication parameters, architecture, components, and system design issues. From this investigation, it reveals that this enhances the SAR operation in a disaster situation. The root cause behind the improvement of these proposed model is the use of three domain collaborative network model. Results of the simulation have shown the favorable performance of CP-AGCM, e.g., in terms of packet delivery ratio nearing 80-90% and optimality of efficient search algorithm.

CHAPTER 5

CONCLUSION

5.1 Introduction

This research work proposes a model, namely the cyber-physical enabled air-ground collaborative model and based on this, a search and rescue system is developed in flood-affected area.

This thesis provides an in-depth analysis of the collaborative cyber-enabled mission-critical model for disaster scenarios from the perspective of wireless networks. It explains in detail the properties of collaborative wireless network and the significant specifications for designing the resilient emergency collaborative network. The implementation of TV white space network in CP-AGCM is motivated by the fact that the specifications which are in harmony with the unique characteristics of wireless network. The develop collaborative search model by considering the propose communication network has fulfilled the requirement of the model. This thesis finds the various key issues to design CP-AGCM by delving into an extensive review of the research contributions which reveal the scope and expose the ideas that are missing in the protocol to improve efficiency. Based on that, it describes a clear roadmap for designing an efficient network for SAR activities in flood-affected areas.

5.2 Contributions

There are three contributions to developing a CP-AGCM in a disaster environment.

1) An extensive investigation has been done on SAR system by considering different wireless technology in order to realize an effective collaborative network model that fulfills objective 1).

2) We have designed a communication network architecture by exploiting TVWS network which makes resilient communication among the rescuers. The designed network architecture helps to communicate faster between the rescuers that fulfill objective 2).

3) We have developed a collaborative search algorithm by considering the proposed communication network. The collaborative search algorithm namely expanding neighborhood search algorithm for multi victims improves the searching performance that fulfills objective 3).

In this thesis, an extensive study has been done about various SAR systems in different scenarios based on existing network technology. Then developed a CP-AGCM by considering different tuning parameters. The essential requirement of CP-AGCM is introduced by considering its architecture, components, suitable existing technologies, and the design challenges. The communication link between PU and CU is studied by choosing the appropriate communication parameters. The selected parameters were: channel frequency CF = 2.4 GHz, PU transmission range =300 m, SU transmission range 120 m and D^2CARP routing protocol. Using these parameters, the studies design the network scenario and investigate its performance by varying the MN with an average inter-arrival time 1000 seconds and network size with 200 nodes. The test results indicate that PDR is becoming better in the case of multi-channel over the single channel. This experiment reveals that the CP-AGCM is appropriate for SAR operation in flood-affected areas than the traditional SAR model.

5.3 Future Directions of the Work

Natural disasters are a very common and adverse event around the world. The main concern about natural disasters is the speed when they occur. The rapid-onset natural disaster includes flooding, earthquakes, tsunamis, cyclones, hurricanes, etc., which damage infrastructure, trigger injury and occasionally huge loss of human life, and pitfall people within the debris. An instant life-saving operation is needed to rescue those people who are stuck and evacuate survivors. The distinction between life and death could be an issue of hours. Preliminary life-saving SAR operations require to arrive extremely fast, possess skilled expertise, and need the suitable latest technology. In this case, some parameters to be considered and the performance of the model can depend on the optimality of these parameters. Also, some temporarily and easy movable technological equipment need to be identified to enhance the performance in flood disaster-affected areas. Some issues are considered in this research. However, this research opens some research issues in the future that can be helped to develop optimization SAR operation exploiting this simulation.

1) This research thought the TV white space as a communication network due to his brilliant characteristics. In this case, selecting a suitable technology is a paramount issue. Next-generation network technology such as 5G can be a good choice for the SAR model in future research.

2) Low data rate and small coverage are two vital requirements of the air-ground collaborative model. The current research shows good performance in terms of these two criteria. Nevertheless, future research can target to enhance the data rate and network coverage.

3) In this proposed model uses the collaborative network. The future work would integrate the collaborative search algorithm with network technology that can be optimized SAR operation in such a hostile environment.

4) Aerial vehicles as UAV or drone could integrate as a base station for rapid develop a communication network after damaging network infrastructure during a disaster. Therefore, the current research can be extended in the future by use network elements equipped aerial base stations.

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