D2D COMMUNICATION BASED DISASTER RESPONSE SYSTEM UNDER 5G NETWORKS

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Declaration

I, Shakil Ahmed, declare that this thesis submitted for the requirements of the degree of Doctor of Philosophy (PhD), from Massey University, is wholly my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualifications at any other academic institution.

Shakil Ahmed
May 9, 2024

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Abstract

Many recent natural disasters such as tsunamis, hurricanes, volcanoes, earthquakes, etc. have led to the loss of billions of dollars, resources and human lives. These catastrophic disasters have attracted the researchers' attention onto the significant damage to communication infrastructure. Further, communication within the first 72 hours after a disaster is critical to get help from rescuers. The advancement of wireless communication technologies, especially mobile devices and technologies, could help improve emergency communication systems. The next generation of mobile networks and technologies such as Device to Device (D2D) communication, the Internet of Things (IoT), Blockchain, and Big Data, can play significant roles in overcoming the drawbacks of the current disaster management system for data anlysis and decision making. Next-generation cellular 5G and 6G network will provide several complex services for mobile phones and other communication devices. To integrate those services, the 5G cellular network will have the capabilities to handle the significant volume of data rate and the capacity to handle traffic congestion compared with the 4G or 3G cellular network. D2D communication technology, one of the major technologies in the 5G network, has the capability to exchange a high volume of traffic data directly between User Equipment (UE) without additional control from the Base Station(BS). D2D communication is used with other cell tiers in the 5G heterogeneous network (HetNet). Thus, the devices can form a cluster and cooperate with each other. As a result, the system tremendously increases network capacity as devices inside the cluster reuse the same spectrum or use an unlicensed spectrum. It will help to reduce the network's traffic load and achieve significant throughput. D2D communication also has the ability to increase area spectral efficiency, reduce device power consumption, outage probabilities and improve network coverage. All of these characteristics are vital parameters for public safety and emergency communication applications.

IoT paradigm is another promising technology with exciting features such as heterogeneity, interoperability, and flexibility. IoT has the capability to handle vast amounts of data. This huge amount of data creates Data security and data storage problems. Though, there are many technologies used to overcome the problem of validating data authenticity and data storage. Out of them, the Blockchain system is one of the emerging technologies which provides intrinsic data security. In addition, Big data technology provides data storage, modification, process, visualisation and representation in an efficient and easily understandable format. This feature is essential for disaster applications because it requires quickly collecting and processing vast amounts of data for a prompt response. Therefore, the main focus of this research work is exploring and utilising these emerging technologies (D2D, IoT, Big Data and Blockchain) and validating them with mathematical modelling for developing a disaster response system. This thesis proposes a disaster response framework by integrating the emerging technologies to overcome the problem of data communication, data security, data analysis and visualisation. Mathematical analysis and simulation models for multiple disaster sizes were developed based on D2D communication system. The result shows significant improvement in the disaster framework performance. The Quality of Services (QoS) is calculated for different scales of disaster impact. Approximately 40% disaster-affected people can get 5-10 dB and approximately 20% users get 20-25 dB Signal to Interference and Noise Ratio (SINR) when 70% infrastructure is damaged by a disaster. The network coverage increased by 25% and the network lifetime increased by 8%-14%. The research helps to develop a resilient disaster communication network which minimises the communication gap between the disaster-affected people and the rescue team. It identified the areas according to the needs of the disaster-affected people and offered a viable solution for the government and other stakeholders to visualize the disaster's effect. This helps to make quick decisions and responses for pre and post-disaster.

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Acronyms

D2D- Device-to-Device communication
IoT- Internet of Things
WSN- wireless sensor network
LTE- Long-Term Evolution
LTE-A Long Term Evolution Advanced
QoS- Quality of Service
SINR-Signal to Interference & Noise Ratio
DRS-Disaster Response System
MANET- Mobile Ad hoc Network
LoRa- Long Range
LAN- Local Area Network
WAN- Wide Area Network
WLAN- Wireless Local Area Network
PAN-Personal Area Network
OFDM-Orthogonal Frequency Division Multiplexing
HetNet-Heterogeneous Network
3GPP-3rd Generation Partnership Project
PPP-Poisson Point Process
PSO-Particle Swarm Optimization
BOA-Butterfly Optimization Algorithm
LEACH-Low Energy Adaptive Clustering Hierarchical routing protocol
HLF-Hyperledger Fabric
PoW- Proof of work
LSTM-Long Short-term Memory
DNN-Deep Neural Network
HDFS-Hadoop Distributed File System
YARN-Yet Another Resource Negotiator
ROC-Receiver Operating Characteristic
AUC-Area under the ROC Curve

Chapter 1

Introduction

1.1 Introduction

Natural disasters such as earthquakes, tsunamis, hurricanes, catastrophic summer floods, severe weather, and wildfires are increasing around the world today, because of urbanisation and the increase of global warming. They have a devastating effect on buildings, transport, power grids, utility services, and communication systems structure. According to the Centre for Research on the Epidemiology of Disasters (CRED), in 2012[1], 387 mid- and large-scale natural disasters were registered, where 185 million people were affected worldwide, including losing their lives and property. The highest number of disasters in 2022 occurred in Asia (137), followed by the Americas (118), Europe (43), Africa (79) and Oceania (10), with an estimated economic loss amounting to US $223.8 billion globally. Figure-1.1 (a) and (b) shows the number graph of death and economical loss from the year 2010-2022.

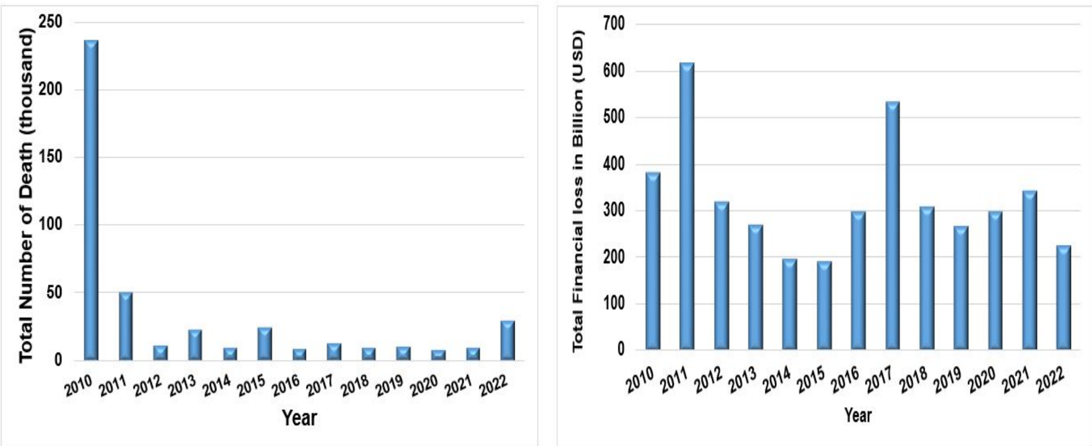


Figure 1.1: (a) Total Number of death in thousand (b)Total loss in Billion (USD) [1].

In 2021, approximately 30704 people lost their lives due to natural disasters.

However, the number of deaths decreased over the decade.They have decreased to at least twenty times lower than these peaks. The percentage of significant fatalities in the Asia-Pacific region is 48%, followed by the USA at 34%. In 2021, a significant number of people (2248) died in the Haiti earthquake. Seasonal flooding in India caused 1,282 deaths. Tropical cyclone Rai was also the deadliest natural calamity[2].

Though it is impossible to control natural disaster calamities, lives and property could be saved from damage by using the appropriate technologies. Emerging communication technology could significantly improve a Disaster Response System (DRS) that would help prevent life and death damage in disaster-affected areas. An innovative DRS helps establish communication between the affected people and the rescue authorities. Disaster-affected people struggle to communicate their situation or are unable to seek help because of the lack of existing communication infrastructure, which might have been destroyed during a disaster[3]. Some giant companies have introduced some communication features on social media. For example, Facebook has implemented a messages safety check feature of a safety report on the feed news.

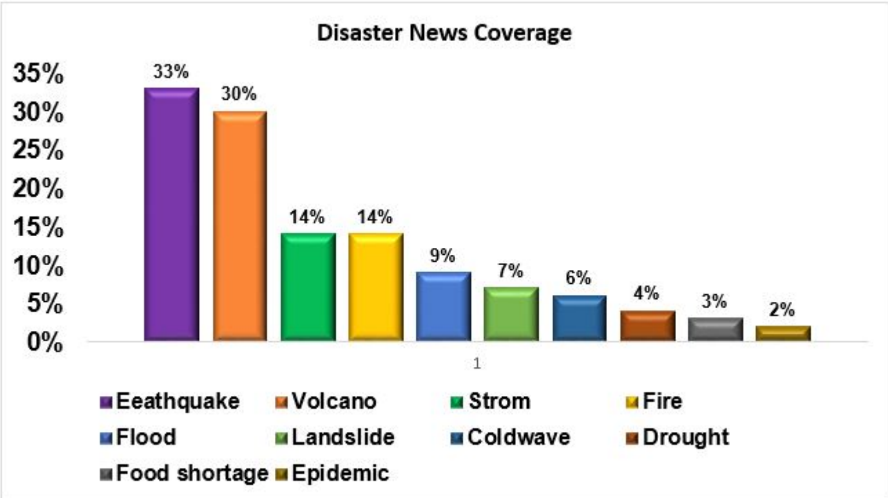


Figure 1.2: Percentage of Different disaster news coverage [4].

Data consistency is one of the vital issues for data quality after a disaster. Today, data reporting, processing and recording are very advanced, but the reporting number has increased drastically. Many reported missing after disasters are nevertheless not known about by appropriate agencies. Figure 1.2 shows the proportion of each type of disaster that receives news coverage[4]. The graph shows that the highest news coverage occurs in the case of earthquakes, which is below 40%.

There are minimal opportunities for local authorities to react to the information as there is a flood of Facebook and Twitter messages seeking help[5]. Because of the current cellular network's high traffic volume and limited capacity, these may lead to misconceptions. Emergency communication infrastructure is one of the vital problems in mid and large-scale disasters. Critical data and voice communication between responder and victim is crucial in an emergency communication system. Many countries suffered significantly in terms of lost lives and properties because of the lack of an emergency communication network. The emergency communication network plays a vital role during a disaster, helping locate people in the affected area, rescuing them, and exchanging vital information to save their lives. However, there are many constraints to the emergency communication network, such as power and traffic congestion, network interference, physical mobile tower damage, road network damage,etc [6].

1.2 Problem Statement

During or after a large or medium range disaster like a hurricane, tsunami or earthquake strike, the importance of highly instantaneous broadcasting tools such as radio and wireless systems and internet services for mobile phone, smart phone laptop, tablets and hand-held devices becomes obvious. A mobile phone is one of the especially important tools for voice communication and internet access can confirm safety and provide different emergency services. Due to the reduced processing ability and traffic congestion the call dropping problem intensifies. Call dropping is caused by lack of available radio channels and available network capacity which varies unpredictably. Services stupendously increase just after the event when people from the affected zones are desperately seeking to communicate with others both inside and outside the disaster-stricken zones. Power failure, traffic congestion, damaged network infrastructure of the traditional communication systems (UE depends on BS) leads no communication in the disaster region. Entire regions suffer from degraded communications, and the remaining capacity is exhausted by the demands of the victims.

However, it can be seen that there is much research going on to overcome communication problems during disaster response. Still, there are some limitations to establish communication in the disaster affected area.

Integrated Framework- There is no existing framework of integration of emerging technologies such as IoT, D2D, 5G which will help to establish communication during a disaster. Integrating these technologies' enhanced capabilities, interoperability or reduction in energy consumption, would allow for a better Quality of Service (QoS) to the users.

Traffic congestion - The demand for telephone service significantly spikes. Voice calls and test messages saw a surge in traffic, up to 50 times and up to 10 times compared to normal volume respectively.

Loss of energy/power - The main cause of outage was a lack of electricity.

A disaster preparedness plan needs to focus on the energy/power; in particular, the plan needs to address such failure facts for entire system or architecture.

Low reliability - Data collected from a variety of sources does not provide validity and authenticity to the data.

Limited services-This causes many problems such as inter-operability among different teams. With limited services, it is not scalable enough to support additional users.

Limited resources - The communication may be lost due to limited resources on site and time is the big constraint to provide and install equipment on affected area.

1.3 Selection of Technologies

The breakdown of telecommunication infrastructure (full or partial) is due to some mid and large-scale disasters, for example, earthquakes, tsunamis, volcanic eruptions, and tornados. This broken communication causes a delayed response from the victims and the rescuers. In addition, power failure is another important cause of the disconnection from the emergency communication network. Though some small communication devices run on battery power, their energy could drain out quickly [7]. Because of physical damage and power failure, resources and services become very limited for communication. Even where there are cell towers and power, traffic congestion could stop providing communication service because of the high volume of data. There is another issue with processing this high volume of data: Secure and valid data needs to be processed fast and efficiently, which will help get accurate information about the disaster. These also help the rescuers decide what to prioritise. Unfortunately, the existing disaster response framework cannot handle these critical disaster events [8, 9].

For an effective disaster response system, an emergency communication system must consider the latest wireless mobile technologies like D2D, IoT, 5G network, Big Data, Machine Learning (ML), and Artificial Intelligent (AI) [10]. It is necessary to integrate those technologies to fulfil the requirement in mid or large-scale disasters like tsunamis and earthquakes. With the help of the technologies, it is possible to make an intelligent disaster framework, which can establish communication, manage the security and privacy of data, analyse the information and make a fast decision to minimise the timeline for the response system [11].

Device to Device (D2D) communication is defined as direct communication between two mobile users using user equipment (UEs) without a Base Station (BS). D2D can bypass the BS as this communication uses the same licensed radio resource, which establishes a direct local link. During natural disasters like earthquakes or hurricanes, urgent communication networks can be established using D2D functionality in a short time, replacing the damaged communication network and Internet infrastructure. The coverage extends by multi-hop cooperation between the devices, which can be used to communicate in cases of no coverage zone, coverage holes, and emergency [12]. Hence, D2D links in future cellular networks are vital enablers for traffic off-loading, reducing access delays, optimal resource utilisation, capacity and coverage enhancements, and energy-efficient communication. It can also reduce power consumption and also can execute power harvesting. In addition, D2D communication includes reducing latency, enhancing spectral efficiency throughput, and creating an Ad-hoc network during mid or large-scale disasters where BSs are partially or entirely damaged [13].

D2D based Internet of Things (IoT) devices can provide portable, accessible, transfer data in a real-time and energy-efficient system when used in numerous situations in disasters. Moreover, IoT can establish a seamless connection for communication and real-time parallel analytics. IoT can also manage smart devices, monitor them, and even distribute processing capabilities [14]. IoT can play other essential roles in disaster monitoring, response and management. Furthermore, in recent years, almost every intelligent embedded system (such as smart cities, healthcare systems, intelligent vehicles, agriculture, transport, and robotics), uses IoT, D2D and IoT technology to help provide communication connectivity and data transfer solutions. However, data comes from different sources, different platforms and different formats. Secure and reliable data is essential to make a better decision based on the unorganised data source [15]. Blockchain and Big data technology may help us to overcome this problem.

Blockchain is a peer-to-peer technology used to record information in an immutable and secure ledger. The risk of altering and changing the stored data within the Blockchain ledger is low. It consists of a digital ledger of the transactions stored in the distributed network of the computer systems on the Blockchain system. The block's body consists of the block header and several transactions. The maximum number of transactions of a block depends on the size of the transaction and the block size. An asymmetric cryptography algorithm is used to secure and validate the transaction . As well, a digital signature uses an asymmetric cryptography algorithm in an untrustworthy environment—public and private keys used for authentication, authorisation, and digital signature validation [16]. .

On the other hand, Big Data is defined as the technological paradigm which consists of a large dataset. Big Data use a scalable architecture that can handle the high volume, variety of data storage, and process[17]. It collects scientific tools to handle and process the enormous volume and vertices of historical data or live streaming data. Big Data not only solves the storage problem but also solves the problem of accessibility and visualisation of the data. To analyse the raw data and process it, ML and AI are very effective. Machine-learning (ML) can help make accurate answers for decision-making during urgent circumstances. For example, ML helps to decide about a disaster prediction before it strikes and the impact of the disaster. It can classify the needs of disaster-affected people. In addition, there are many different algorithms/ models of AI/ML, which also help to use decision-making (prediction/ regression and classification) of different types of problems in various domains. Researchers can now conduct massive data analyses to produce precise information quickly using these technologies [18].

The discussion above concludes that using emerging technologies- D2D and IoT for the next-generation network can make an effective emergency communication framework. This framework generates instant data for the response systems about the disaster so that people can be aware of it, take precautions and organize help and distribution of appropriate resources, which lead to preventing and minimising the loss of lives and properties.

1.4 Research Purpose and Motivation

Many countries have suffered significantly in terms of loss of lives and properties because of the lack of an emergency communication network. An emergency communication network plays a vital role during the disaster because it helps to locate people in the affected area, rescue them, and exchange vital information to save their lives. However, there are many constraints upon the emergency communication network such as power, traffic congestion, network interference, physical mobile tower damage, etc.

During the Christchurch earthquake on 22 February, 2011, there was huge damage to network towers, power cable failures, traffic congestion, electric outage, communication equipment damage in the surrounding areas. As a result, the affected people were not able to make emergency and other priority calls just after the earthquake struck. Even cordless phone systems stopped working as there was electricity failure. Figure 1.3 shows the power and communication infrastructure failure map after the earthquake in Christchurch. In the area where the communication network was partially damaged, network traffic congestion occurred due to the large volume of calls attempted from that area. It affected directly the backup battery in the cell tower. As a result, telecommunication performance became limited or the lack of coverage increased significantly.

Though XT network operational outage was fully restored six days after the disaster had struck Christchurch, the CDMA network was only fully operational after nine days. The CDMA network required much more time to restore the power outage as compared with the XT network, because the CDMA network needed much higher capacity generator than XT network. On the other hand, the PSTN cabinet required less time to restore functionality compared with the cellular network [19].

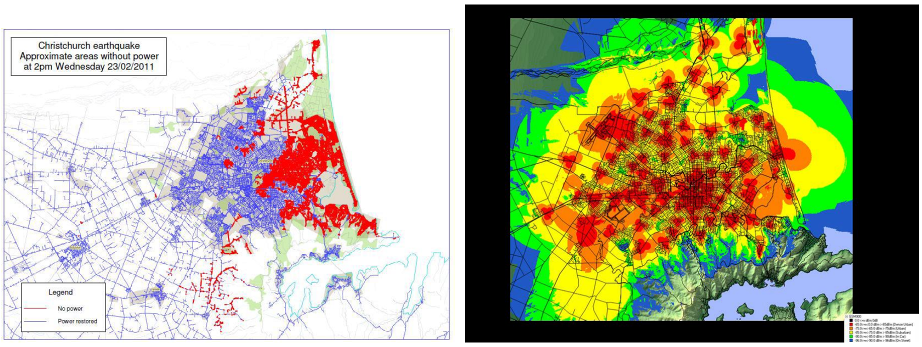


Figure 1.3: (a) Power failure map. Source: Vector (b) 2degrees' 2G and 3G sites. source: 2 Degree [19].

However, when disaster strikes the first 24 hours is a very crucial time for communication. Effective emergency communication must take place for rapid response to the effective area. Deployment of an emergency communication system can provide information to the affected people about where to get medical support, where and how to reach the safe place, and where they will get pure drinking water[20]. Though there is much research carried out using the latest technologies like IoT, Device to Device (D2D) using older 2G/3G networks separately to overcome the problem of emergency communication system is ineffective. Unfortunately, there has been very limited research done to integrate IoT, D2D and fifth generation (5G) mobile technology in disaster response systems. Thus, integrating IoT and D2D under the next generation of mobile communication networking can provide much required improvements for the disaster response system. This could save many lives and property by providing effective emergency communication during a disaster.

1.5 Research Questions

1. How does the D2D communication perform in terms of coverage probability, QoS and energy efficiency in different disaster scales?

2. How to reduce the energy consumption for data communication, enhance the network lifetime and improve the clustering and routing protocol?

3. What are the secuirty risks for the D2D data communication and how to overcome these security risks?

4. How to handle the large volume of data from the different sources? How to process and analyse the structured and non structred data to make quick decisions?

1.6 Research Objectives

Communication equipment damage, electricity outages and traffic congestion adversely affect the communication network. Without smart emergency communication infrastructure and proper communication, it is not possible to help the affected people. A smart emergency communication framework could save many lives.
The objectives of the research are the followings:

1. To propose a disaster response system framework by integrating the emerging next generation communication technologies to enhance the response time and reliability of the system.

2. To analyse the performance of D2D communication for extending the coverage, enhancing energy efficiency and QoS communication in the DRS network.

3. To analyse and improve the D2D based IoT network for data transmission protocol and extend the network's lifetime.

4. To examine the security issue of D2D communication and propose a security model for the disaster response systems.

5. To analyse and visualise the massive amount of disaster data more accurately and precisely to minimise the response time and significantly improve the DRS framework.

1.7 Research contributions

This research contributes to establishing and integrating the latest technology to overcome the drawbacks of the DM network, which includes all of: infrastructure and hardware failure, network connectivity, energy deficiency, unpredictabilities, limited resources, system complexity, unorganised data, data security, privacy and other factors. The contribution of the research are the following:

- Investigated the performance of D2D communication for the different scales of disaster impact. The simulation model identified the performance of D2D communication requirement for the small to large scale disaster.

- Proposed a novel clustering and routing algorithm. The proposed algorithm's fitness function preserves the residul energy for the nodes which increases the nodes' lifetime. This will help to enghance the netowrk lifetime and also increase the number of packets that transmit to the BS.
- Proposed a novel data security model for both the pre and post disaster D2D data security. Deployed the HLF based environment to investigate the performance of the HLF based D2D data security.
- Proposed and implemented the data processing model to measure the performance of the disaster data storage, processing and analysing. A large amount of unstructured disaster data (syntetic and social media data) was analysed using Big data technology (Hadoop and Spark distributed) framework.

1.8 Thesis Outline

The main focus of this thesis is to integrate technologies to enhance the disaster response system's connectivity and performance, which will also reduce the time frame of the response system. The work analyses the DRS network and determine whether the problem of energy efficiency communication, data security, data analytics, and visualisation can significantly improve the response system. The cluster-based communication in D2D and IoT is used for energy efficient data collection and communication establishment. Blockchain ensures that the data security and deep learning system is used to analyse and visualize the data. The outline of the thesis is as follows:

Chapter 1 introduces the emergency communication needs in a rapid disaster response system; briefly discusses prospects of D2D, IoT in disaster response system as well as emergency communication systems.

Chapter 2 consists of an in-depth literature review of the disaster response system phases, communication issues and data analysis problems. This chapter also discusses the technologies used to integrate disaster response systems to overcome the current problem for the framework. This section also includes a comparison of the previous system with the current system.

Chapter 3 proposes to integrate D2D communication for the disaster response system. This technology provides the robustness of the DM framework. A theoretical analysis for the extended coverage is performed and cluster-based communication in different disaster scales is discussed. A clustering algorithm for energy efficient data communication is proposed. This chapter also analyses the services users can use in disaster regions for disaster impact. An in-depth analysis of the energy efficiency, extended coverage and enhanced overall network performance is also presented in this chapter.

Chapter 4 analyses D2D based IoT technologies' ability to reduce the impact of the disaster response system. The network's main problem is energy efficient data communication and transmission. In this chapter, a clustering and routing algorithm for the D2D based IoT network is proposed.The simulation result shows that the proposed algorithm significantly improves the network's lifetime.

Chapter 5 described D2D communication data collection from different IoT devices. Cluster-based communication needs some authentication process to validate the integrity of these data. In this chapter, a novel model using Blockchain technology for the data collection for both pre- and post-disaster is proposed. This chapter also provides a deep analysis of the proposed model regarding the system performance.

Chapter 6 analyses the disaster data for different disaster scales. The big data technology is analysed and measured the performance of the proposed system. Data is collected considering the D2D communication during disaster for further analysis. This chapter also analyses different machine-learning models which can perform better for disaster data. A disaster data workflow is proposed, analyse and visualize for the data efficiently so that the first responders can take necessary action for the people affected by a disaster.

Chapter 7 concludes the thesis by providing a summary of the contribution of the research. The summary briefly describes the system's performance. This chapter also discusses the future direction of the thesis.

The summary of the research problem, proposed solution and structure of the thesis are given in figure 1.4. The research improves communication network coverage, QOS, network lifetime and data security in disaster events.

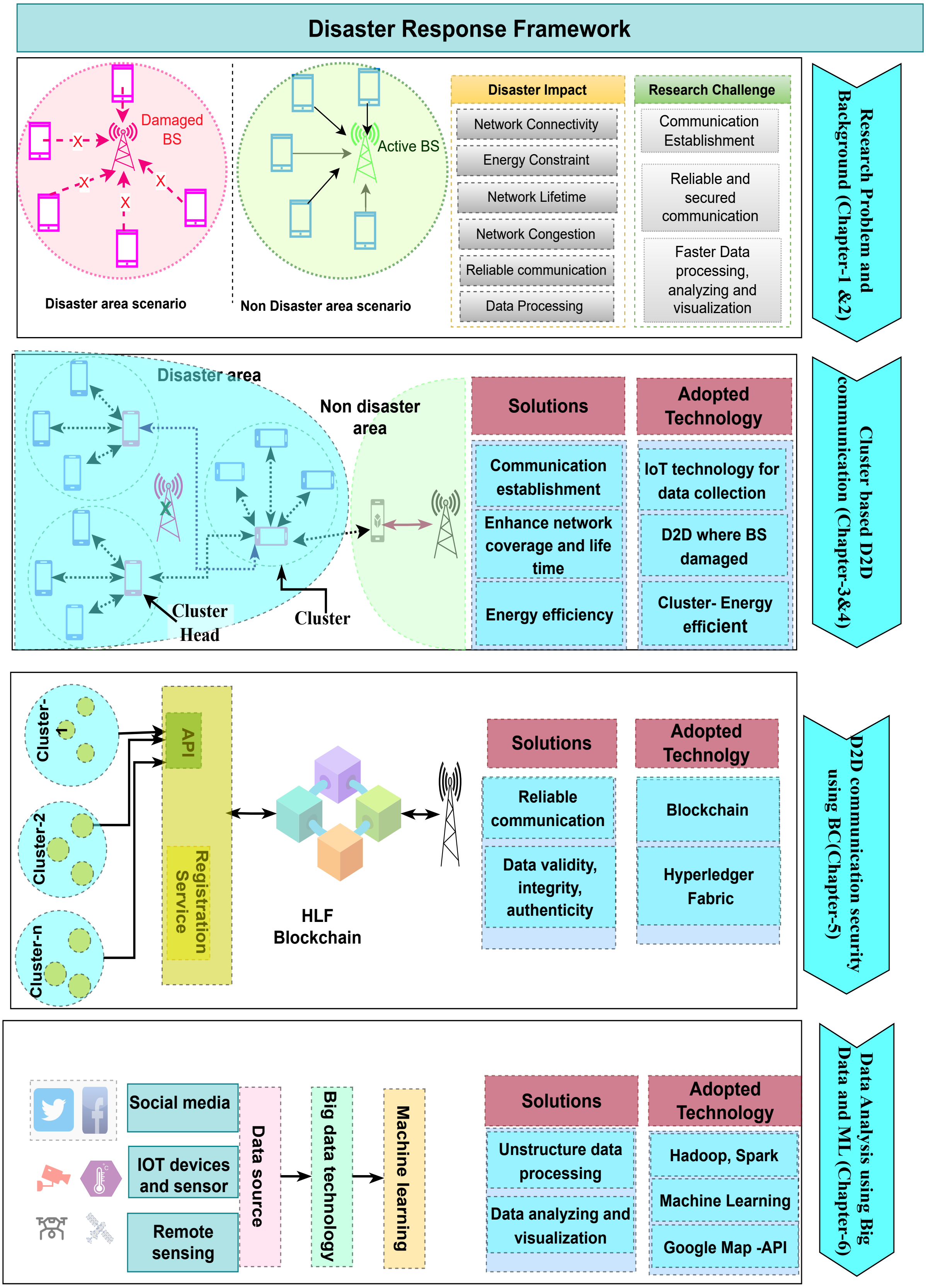


Figure 1.4: Overview of the existing system and contribution of this thesis.

1.9 Publications

- S. Ahmed, M. Rashid, F. Alam and B. Fakhruddin, "A Disaster Response Framework Based on IoT and D2D Communication under 5G Network Technology," 2019 29th International Telecommunication Networks and Applications Conference (ITNAC), Auckland, New Zealand, 2019, pp. 1-6, doi: 10.1109/ITNAC46935.2019.9077975.

- S. Ahmed "Study of Cluster-Based D2D Communication in Next Generation Mobile Network for the Post-Disaster Response." 25th IEEE International Conference on Advanced Communications Technology (ICACT) at Phoenix Park, PyeongChang Gangwon-do, Korea.

- S.Ahmed, "A Novel Data Security Model of D2D Communication Using Blockchain for Disaster", International Conference on Computer Science, Information Technology and Engineering (ICCoSITE 2023)

- S.Ahmed "Bio-Inspired Energy Efficient cluster-based Routing Protocol for IoT in Disaster." Journal of Sensor and Actuator Networks, MDPI (Under review)

- S.Ahmed, N. Ahmed, "Big Data Analytics For The Disaster Response System Using Apache Hadoop Spark And Deep Neural Network", IEEE Transactions on Machine Learning in Communications and Networking (Under review).

Chapter 2

An Overview of D2D Communication for Disaster Response System

2.1 Introduction

Technology plays important role in saving lives, property and other valuables after mid or large-scale disasters. It helps to identify the location of the victim, provides current information about the situation and is also able to contact and help people by exchanging information. The first 72 hours after a disaster are crucial for the success of a disaster response system [20]. Within this period, a response and recovery plan needs to have been implemented in order to save lives. Doing that requires gathering information from the affected area, thus data security and privacy, and faster data analysis play vital role in making decisions. It also helps if the the rescuer team has an an effective and efficient rescue plan, and that it is prioritised without duplication. Fortunately, several technologies provide enormous functionalities to enable this. In addition, one of the existing technologies might fulfil the requirement of all the phases of disaster. There is a need to integrate the latest technology into the framework to ensure the success of the DM framework. It is very important for disaster responders to use the latest emergency communication framework technology to minimize the gaps in the existing system.

This chapter provides a brief overview of the emerging technologies which can be used for the prompt disaster response system. This chapter also briefly discusses the different technologies used for disaster response systems, analysed them and explained how technology could help to improve the emergency network. The methodology used to conduct the research is also briefly discussed end of this chapter.

2.2 Disaster Response System

Disaster Response System (DRS) is a symmetric method involving all the disaster phases of planning, managing, rescue, response, recovery, mitigation, and monitoring. The system collaborates with government agencies, first responders, volunteer organisations, and public sectors agencies. The intelligent DRS aims to minimise the disaster's impact and clearly understands analysing, monitoring and predicting the consequences of the disaster's impact.

Disasters can be classified into human errors, (industrial explosions, pollution, chemical reaction, and urbanization affecting the environment, considered a human-made disaster) [21] and natural disasters causing both human-made and natural imbalances, including earthquakes, tsunamis, typhoons, tornadoes, etc. Excellent DRS is crucial in reducing the disaster's consequences. Disaster response system can be defined as a framework or a process of effective preparedness, awareness, responses, communication, and prompt response to the disaster[22]. It also includes proper analysis of the total damage, and people's needs (water, food, medical attention, medicine, etc.) to summarise the damage, organise the available resources and distribute responsibilities to the responders to minimise the disaster's harm. There are three phases of an effective disaster response system [23]:

1. Pre-disaster phase: Effective DRS in this phase can reduce the loss of human life, resources, and structure when a disaster strikes.

2. Disaster phase: this phase safeguards people's needs, makes available resources and proper communication, and minimizes suffering.

3. Post-disaster phase: this phase is includes successful prompt response and durable recovery. It also includes victim rehabilitation and relief programmes.

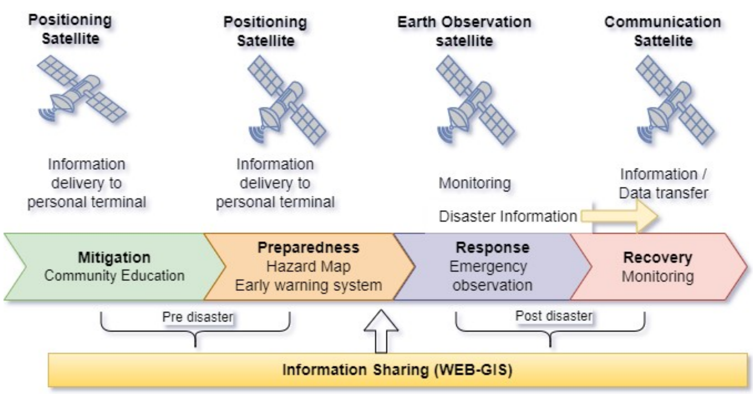


Figure 2.1: Different types of disaster phases.

Figure 2.1 shows the different disaster phases.

2.3 Pre-Disaster Phase

2.3.1 Prevention and Mitigation:

Prompt response reduces the intensity of the disaster damage on a large scale. The terminology of prevention uses the term 'encirclement' to refer to the vast diversity of measures that protect people, property, and security [24]. However, it is impossible to prevent natural disaster damage, so the prevention phase is more about reducing the damage caused by large-scale disasters. On the other hand, the term 'mitigation' refers to all necessary actions to reduce the disaster's effect. It also includes the reduction of vulnerability conditions caused by the disaster. This mitigation also helps to reduce the damage scale for future disasters.

2.3.2 Preparedness

The terminology of 'preparedness' refers to taking precautions with all crucial factors that could help to reduce the disaster's damage. The process involves the government, fast responders, communities, and individuals responding accordingly to the disaster's effect, so that agencies and the people can cope with the situation promptly and efficiently[25]. Preparedness involves a diversity of factors, including adapting multiple emergency response plans. Other factors for preparedness involve developing an early warning system using the latest technology and creating awareness in people about disasters by providing education, and training individual personnel [26]. This training and education includes search and rescue operations of the evacuation plan and area, which are most effective in the event that a disaster occurs. It also involves the preparation of demonstration practice, including all the responsible agencies and individual personnel. These processes also need to be supported by appropriate policies, rules and regulations and budgetary provisions.

2.4 The Disaster Phase

2.4.1 Response

Response refers to the first phase during or after disaster occuring, which is also a critical phase for the success of the disaster response system. This stage involves communicating with the disaster impact area people, setting up the response control office, issuing the further warning (tsunami) evacuation plan, distributing the rescue plan, and providing food and a water medical kit if necessary [27]. Sheltering people is made a priority task according to the needs of the people. Emergency relief is undertaken in this phase during and immediately after the disaster, including relief to homeless people, provision of drinking water, security, damage assessment and debris clearance.

2.5 The Post-Disaster Phase

2.5.1 Recovery

This phase refers to the activities that encompass emergency relief, rehabilitation and reconstruction [28].

2.5.2 Rehabilitation

This phase includes using temporary public facilities and housing and providing other facilities that require long-term recovery[29].

2.5.3 Reconstruction

This phase refers to all the functionalities enabling a return to the normal condition, which was the pre-disaster phase. Reconstruction returns the communities to everyday life by replacing the buildings and infrastructure, including communication equipment and all the necessary facilities required to feel personal safety and comfort [30].

2.5.4 Development

This phase includes the long-term ongoing economic and infrastructural development process. Better and more developed infrastructure could reduce the effect of the disaster. For example, constructing a modern house against flooding should make it capable of handling the onslaught of heavy rain or wind speed [31]. In addition, it should be able to withstand high-scale earthquakes, increase the planting of trees to reduce landslides, and provide backup communication infrastructure and facilities so that communication can be done seamlessly.

2.6 The Disaster Impact

The disaster impact refers to the real-time natural disaster effects and the risks involved during the disaster. The duration of the disaster impact depends on what type of disaster it is. For example, an earthquake or typhoon can occur in a few minutes, whereas a flood or wildfire can occur over an extended period.

Both the pre- and post-disaster phase elements are independent [32]. Prevention, mitigation and preparedness involve the pre-disaster response phase. This phase is one of the critical parts of a successful disaster response system. Proper planning and preparation can reduce not only the impact of the disaster but also can save many lives. In addition, time is one of the crucial parameters to measure the success of DRS in this phase. A prompt response can save lives, wealth and property. As this phase depends on both pre- and post-disaster phases, an effective and efficient DRS is required [33]. Post-disaster phases, involving emergency relief and rehabilitation, are vital activities. The success of a disaster framework depends on the proper planning and ongoing development of the infrastructure. This phase also plays an essential role in the disaster framework by the whole realm of activities during the disaster [34]. The entire disaster framework depends on resource planning and resource allocation at all stages of the disaster cycle. To make this happen, assessment of damage, people's needs during and after the disaster, faster analysis of the situation, and prompt decisions are crucial. That is why establishing communication with disaster-affected people is vital to collect the data from them and analysing it so that quick decisions are made. This will maximise the overall success of a disaster response system.

Table-2.1 shows the types of decision making services and agencies' involvement in the DM network.

Table 2.1: Types of decision making services for the DM.

Decision Making Services	**Agencies and Infrastructure**
Emergency medical care	Hospital, doctor, first aid education and training programme
Public safety	Police, transportation management
Health and sanitation	Water and waste management
Communication	Communication infrastructure, telecom engineer
Housing	Public service and utilities, fire service
Food	Supply chain management, relief management, volunteer

2.7 Background of The Study

Disaster response system success depends on the framework or system used in the disaster area. After a large-scale disaster, it is very important that technology remains available for the affected people. So that affected people can communicate quickly to exchange information about their location, condition, and needs with the first responders. The table 2.2 below shows the necessary components for the response after the disaster.

Table 2.2: Disaster response system parameters.

Requirement	**Parameter**
Prompt response	Rapid deployment of emergency communication infrastructure, localise victims.
Interoperablity	Integrate/able to cooperate with existing system.
Traffic free operation	Must be clear voice/text/data transfer.
Network coverage	Enable to extend network coverage around disaster area.
Network capacity	Must be capable for different types of devices and system.
Easy use and low cost	Should be low cost and use simple available equipment.

For the last few years, with the increasing number of cellular users generated a high volume of data from the UE. These traffic data are increasing day by day. To accumulate this high volume of data demand, the next-generation mobile network is required. The situation is the same during a disaster where a high volume of traffic data is generated. The 4G network provides a good quality user experience as a mobile service. However, during a disaster, 4G does not have the capabilities to handle such a high volume of traffic and the channel becomes congested. Moreover, during a disaster, there is no guarantee that network infrastructure will exist. As a result, the researcher focused on the 5G based disaster response system. “5G network is able to reconfigure and enhance the resilience of the network which gives the network flexibility. These characteristics are the most important to establish a communication disaster scenario. Moreover, 5G also provides faster communication, higher throughput, can integrate emerging technologies like IoT, D2D.

D2D communication is very effective in a disaster scenario as the D2D communication system is able to establish communication between different nodes in the disaster area without depending on the base station [35]. This is a very important characteristic to establish a prompt communication system in a disaster situation. D2D-based communication has the ability to allocate spectrum efficiency which allows the system to upload content in the UE without time delay. Moreover, D2D communication is capable of communicating directly between two devices without a network infrastructure [36]. As a result, D2D communication has the ability to offload cellular traffic, consume less power, and provide higher throughput. These characteristics make researchers attention to using D2D communication in the high density of UE sharing the same cellular resources where there are limited connectivity and coverage.

On the other hand, there is much research that uses IoT/ Wireless Sensor Network(WSN) for disaster management, especially post-disaster response [37]. The system used in WNS is considered the part of IoT where there is a distributed node for senses and actions. IoT features and characteristics bring an amazing solution for the agriculture, disaster, security and communication sectors. It has features like low consumption, interoperability, and lightweight. However, IoT devices protocol allows seamless connection, to access secure information and discovery of objects. Moreover, it uses IEEE802.15.4 standard, 2.4 GHz frequency and IpV6-Low Power Wireless Personal Area Network (6LPAN) makes IoT appropriate for the post-disaster-related parameter mentioned in the table above. Though, there is much research that provides the solution for disaster response based on IoT, WSN, and D2D[38].

Luo et al.[39] proposed a solution based on WSN and Mobile Ad hoc Network (MANET) connected with the satellite and mobile network. This communication system will be deployed in the disaster-affected area to communicate with the affected people and the rescue team. On the other hand, the area which is not affected after the disaster will use the cellular gateway to connect with the satellite. According to the location and wireless network coverage condition, affected people will select the path of communication. For this communication, Fujiwara et.al[40] describe a routing protocol. The proposed routing protocol relies on the hybrid wireless network (ad-hoc wireless network with the mobile network) and is mainly used for emergency disaster communication for seamless connection. During a disaster when the mobile network with the UE disconnects, the UE cluster moves to an ad hoc node and is able to restore using the multihop connection. This connection reduces delay time. However, only a small amount of data can be transmitted which will not fulfil the requirement of the highly dense area.

Javad.Z. Moghaddam .et al [41] proposed combined with Cognitive Radio (CR) and D2D for the emergency communication network for a prompt response. The authors proposed a hierarchical topology which is based on clusters. This topology is used for the CR network which covers a large area which is a very important factor for the disaster situation. The authors proposed a cooperative beamforming (CBF) technique of CR to D2D communication. A software-defined network (SDN) controlled the communication with the cloud head. Through this technique, communication between devices maintains connectivity [42].

The author proposes a wearable smartwatch or sensor which will allow response through mobile wireless ad hoc [43]. In case of disaster, if infrastructure damages wireless ad hoc networks can play a vital role. The author proposed this IoT device, sensor and other wireless ad-hoc network connected with the city monitoring sensor for communication. A drone supported to establish the connection and used a mobile base station.

Another wearable smart devices-based solution is provided by Dhafer Ben Arbia for critical and reuse operations [44]. The author discusses the reliability of setting up a wireless communication system for offloading data. The proposed system is integrated with a mix of wireless devices Rasberry Pi, and smartphones and uses different communication technologies. This technology includes wifi and Bluetooth for end-to-end connection. For the routing, the author proposed the Optimized Routing Approach for protocol [45]. However, there is a limitation about the connectivity and resources using this technology. This problem is solved by a low-range wide area network or LoRAWAN.

LoraWAN is based on LORA (Short for long range) technology which is long-range, low-power wireless radio frequency technology used for secure data transmission. It uses low-power WAN (LPWAN) protocol and wireless connect battery-operated IoT. LoRA wireless chipset used in IoT applications which uses end-to-end AES 128-bit encryption for secure data transmission to geolocation system and data relay via LoRA WAN protocol. However, it does not have the capability to handle a large volume of data [46, 47].

Big data and IOT have made significant contributions to locating people during disaster scenarios. IOT-based disaster response solution provided using smart Bluetooth which will create a network with enough bandwidth to send critical text-based communication in absence of the internet and without power [48]. these Bluetooth devices can handle 1610kb email messages or over 11001400-byte tweets per second. These will help to localize victims. However, different networking hardware with different frequencies and different software will not allow communication between two devices without the Internet.

For extending the connection during the disaster is discussed using unmanned Arial vehicle (UAV) [49, 50]. This network architecture used 802.11 Wifi, 3G/4G mobile network, ad-hoc network, and satellite. UAVs has a faster deployment ability. It is flexible and cost-effective. It can provide on-demand service by providing fly communication facilities in the disaster area. It will provide the extent communication system and make a bridge of communication which affected area where the communication infrastructure is damaged. The self deployed wifi network is used to coordinate with the affected people with the rescue team.

However, there are lots of consideration present to deploy UAV for emergency communication. UAV (Drone) has limited resource for computation capability and has also less sensing power. It has limited power capabilities not able to fly for a long time because of its limited power. Moreover, it has limited capabilities to provide stable, secure communication and provide only low altitude based communication [51].

For higher altitudes, Google deploys ballon based emergency communication system. This system provides the altitude 18Km from the ground. It has the ability to provide internet facilities UAVs or between UAV with the affected people both in large scale geographical area. But in case of adverse weather, it is very difficult to operate [52].

2.8 Technological Aspect

2.8.1 Public Safety Network

Standardisation of technologies is one of the critical factors which guarantees that the technology can enhance interoperability across the service and with products manufactured by different vendors or companies [53]. The long-term evaluation (LTE) standardisation makes the technology commercially acceptable and sustainable. The 3rd Generation Partnership Project(3GPP) standards organisation develops the protocol for mobile telephone technology[54]. This organisation has contributed enormously to developing and maintaining the telecommunication standards from its second generation (2G) to the fifth generation (5G).

The primary long-term evaluation (LTE) architecture was standardised as 3GPP LTE, which was released on 8/9. Both 8 and 9 releases use the bandwidth 1.4, 3, 5, 15, and 20 MHZ. This provides the support of numerous development scenarios [55]. The 3GPP release 10 brought the LTE-advanced or LTE-A. The main focus of LTE-A is the carrier aggregation technique that enhances the network capacity. It combines two or more carrier components for higher data rates that increase the overall bandwidth capacity of the existing mobile network [56].

Globally, all the public safety organisations and agencies adopted the large-scale deployed LTE for public safety networks. Public safety network supports the 700 MHz P25 narrowband network's data application to 700MHz LTE broadband network data-intensive application [57]. This application included voice and narrow bandwidth data-centric applications. The allocation of the LTE broadband for the public safety network is shown in figure 2.2 [57].

Heterogenous Network development (HetNet) and coordinated multipoint transmission and reception (CoMP) are established from 3GPP's release 11 [58]. 3GPP release 12 introduced D2D communication in LTE-A architecture. It also increases

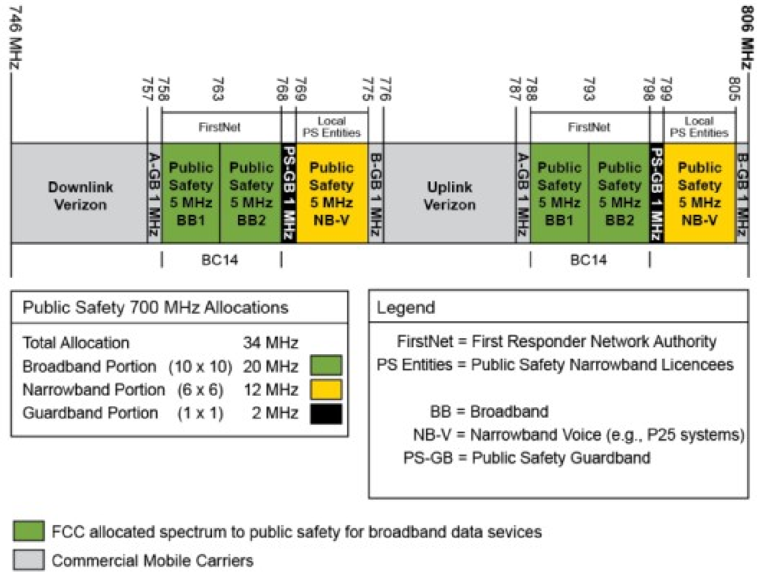


Figure 2.2: LTE broadband for the public safety network [57].

network capacity and cell coordination, enhances coverage area, and reduces costs. Another vital application released in 12, public safety, had a significant influence on the disaster management system. In the 13 releases, implementing and supporting the critical mission services, D2D is one of the functions of these services.

Release 14 enhances the LTE support for Vehicular (V2X) services[59]. The other essential service for the disaster system is the 5G radio system which was released in 15. Release 16 enhanced the support of the Internet of Things (IoT) and public safety [60].

Wireless communication and advanced mobile telephones help evaluate and transform into an innovative modern-day society. The first wireless communication was invented by an Italian G. Marconi, who communicated the letter ’S’ over a 3 km distance [61]. This communication used electromagnetic wave as a three-dot morse code. After this beginning, wireless communication along with satellite communication, radio, tv, mobile phone and the Internet has become a crucial part of daily life.

2.9 Why 5G in DRS

The evaluation of wireless technology generation considers the factors of data rate, coverage, mobility, and spectral efficiency, all depending on the performance factors of wireless technology. Fifth-generation mobile technology fulfils the demand for wireless data and networks.

1G- The first generation of wireless technology was introduced in 1980, with a data rate of 2.4kbps [62]. Nordic Mobile telephone (NMT), Advanced Mobile phone system (AMPS) and Total access communication System (TAS) are the primary subscribers of the 1G. Voice calls were stored and played in a radio tower. This technology makes the call vulnerable and can easily enable eavesdropping by a third party. In addition, capacity, inferior voice association, rapid hands-off and lack of security were problems inherent in the first generation wireless system.

2G 2G Global System for Mobile Communications (GSM) was digital technology introduced in the Second Generation (2G) mobile network in late 1990. The main focus of the 2G technology is voice communication. It also provided a services Short Message System (SMS) and Electronic Mail (Email) with a 64kbps data rate. Code Division Multiple Access (CDMA) is an effective system introduced in GSM. 2G handsets requires less power as the radio signal requires low power[62].

3G The third generation (3G) was first introduced in late 2000. 3G introduced high-speed mobile access to services, based on the Internet Protocol (IP). It can be communicated with a high transmission rate of up to 2Mbps[63]. 3G also maintains the QoS to improve the voice quality and global roaming. The disadvantage of the 3G system compared with the 2G system is cost and power. The 3G system's handset required high power compared with the previous generation. The cost was also increased for the voice data and network plan. Wideband Code Division Multiple Access (WCDMA), Universal Mobile Telecommunications Systems (UMTS), High-Speed Uplink/Downlink Packet Access (HSUPA/HSDPA) and Evolution-Data Optimized (EVDO) are introduced and used in 3G technology [64].

4G

The 4G Fourth Generation (4G) mobile network is the successor of the 3G and 2G standards. 4G mobile network improves the communication system and is fully based on the IP[65]. In addition, it enhances all the latest technology like voice, data, and multimedia with a high-speed data rate compared with other generations. Some new technology has also been introduced in 4G like multimedia messaging service (MMS), High definition mobile and tv content, digital video broadcasts etc.

5G 5G wireless communications envisages a high scale of increase in wireless data rates, bandwidth, coverage and connectivity. This next generation mobile network consists of a massive reduction in round-trip latency and increases the throughput and energy consumption[66][67]. Group Special Mobile Association (GSMA) is working towards the eventual outline of 5G communication[68]. The major requirements of 5G networks are identified as [69]:

- 1-10 Gbps data rates in real networks. Traditional peak data rate of LTE network is 150 Mbps. Compared with LTE and 5G, 5G is almost 10 time higher than LTE.

- One ms round-trip latency that is almost 10 times lower than traditional 4G networks 10 ms round trip time.

- High bandwidth in the unit area which is required to enable a large number of connected devices with higher bandwidths for longer duration in a specific area.

- An enormous number of connected devices to provide connectivity to thousands of devices for D2D and IoT, emerging 5G networks.

- Seeming network availability is 99.999% to ensure permanent network availability in 5G.

- Almost 100% coverage for 'anytime anywhere' connectivity. 5G will use pico cell to ensure complete 5G wireless networks coverage irrespective of users' locations.

- Reduction in power consumption by almost 90%. Standard bodies considered 5G as a green technologies.

- High battery life. A reduction in power consumption by devices is fundamentally important in emerging 5G networks.

Users and devices are increasing exponentially day by day. It is required to enhance the system's capacity to accommodate these users. Cellular networks are now moving from the traditional connectivity with the base station (eNodeB) to a device-centric network [70]. This is because of the high demand for millisecond latency and current bandwidth limitation in the traditional network. Moreover, with the increasing number of devices and users, it is essential for the wireless industry adopt the advancement of the current network. As a result, they are developing small cell from the initial macro hexagonal cell coverage of every inch of the area and accommodate the huge number of device and user with a seamless connection and services.

By deploying small BS with low power, better network capacity and extended coverage area with zero uncover area is envisaged. Moreover, the overlap of all smal, pico femtocells with the existing macro cells will provide enhanced and efficient frequency reuse[71].

Figure 2.3 shows the evolution of 5G network.

An orthogonal Beam is assigned to the Mobile Base Station, and BDMA divides that antenna beam, based on the BS's location, to provide multiple access to the BS. This beam support increases the capacity of the entire system. Six exciting features make 5G more popular than all other generations: higher capacity, high data rate, massive device connectivity, low latency, extended coverage and QoS[72].

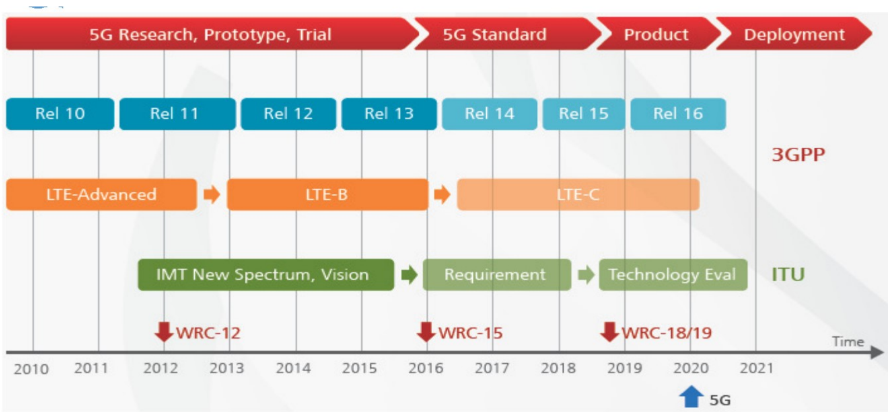


Figure 2.3: Evolution of 5G network [69].

Another exciting feature of 5G is Mobile cloud computing. This service is the integration of cloud computing technology with mobile devices. This service included enhancement of the computing processing system, storage, service and application via the Internet[73]. This service also offers a low-cost, seamless service through existing technology and allocates resources efficiently. The integrated system not only enhances the service but also increases the performance of the mobile devices in terms of memory, energy, computational power and context awareness. The mobile device will act as a resource provider in mobile cloud computing. The number of mobile devices and other devices in the local area will also provide the resource which creates a local cloud [74]. Figure 2.4 shows the resource sharing system of the mobile cloud system. This system provides user mobility and performs col-lective sensing. Mobile cloud computing offers fulfilment of some other cloud services like adaptability, scalability, and availability.

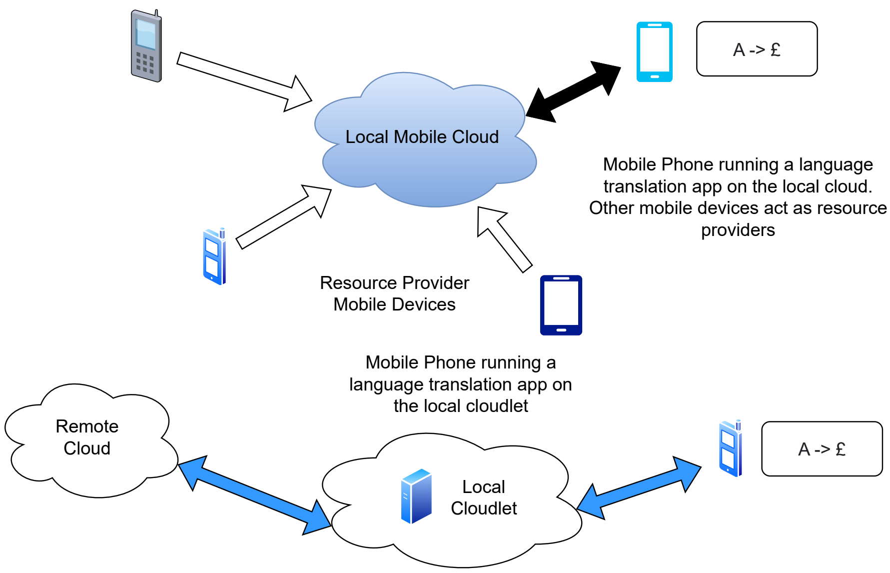


Figure 2.4: Mobile cloud resource allocation in 5G.

Table 2.3: Comparison of 4G and 5G network.

Specifications	**4G**	**5G**
Data Bandwidth	2Mbps to 1Gbps	1 Gbps and higher
Frequncy Band	2 to 8 GHz	3-300 GHz
Standards	OFDMA, MC-CDMA, network LMPS	CDMA and BDMA
Technologies	Seamless integration of broadband LAN/WAN.PAN and WLAN	4G+ advance technologies based on OFDM modulation
Services	HD streaming, Dynamic Information access	4G+ any demand of the useres

All the features described above are crucial for the DM network. A comparison of 5G with 4G is given in table 2.3.

2.10 D2D Communication

3GPP release 12 mainly focuses on the public safety protocol, which the first responder agency, such as firefighters, police, ambulance service or volunteers can use. This communication framework offers several beneficial services for the disaster response system. D2D offers a high quality of service (Q0S), less traffic congestion, reduced network overhead, an efficient spectrum and, most crucially, the energy consumption of the mobile devices in the disaster-affected area [75].

The main aim of this communication system is to reduce the dependence on the network infrastructure. There is no guarantee that network infrastructure will exist during or after a disaster. In addition, the system also focuses on the operation cost and active broadband communication. The two key features of this system are explained below:

1. **Proximity service (ProSe):** 3GPP release 12. The system which permits mobile devices to discover with other mobile devices and communicate in physical proximity, is known as a proximity service[76]. This service allows the discovery of other devices and communication directly without the help of BS. Mobile devices or UE discover another mobile device or UE in their proximity. This is known as D2D discovery, performed directly at the EPC level by the UE. The direct communication between two UE is discovered directly. This can be done by LTE air interface[77]. As this system does not depend on the routing signal via BS reduced the network congestion and could communicate in case of damage or absence of BS or the core network. For direct communication, D2D discovery is not essential as communication can be done via broadcasting. This service is used for public safety and for any other

commercial applications such as disaster frameworks, collection of data and communication[78].

2. **Group communication:** Group communication is one of the essential features of the public safety protocol. This group of communication services considers communication from one to many a crucial criterion during or after the disaster, making it easy to manage and communicate with a large number of people simultaneously [79]. In this mode, all the UE use a standard downlink stream for the communication. This system helps optimise the use of this communication's entire resource. 3GPP multimedia broadcast multicast. In LTE/LTE-A and D2D, both use this group communication which is very useful during a disaster to get enough information and also to fulfil the criteria of the public safety demand[80].

There are three coverage scenarios to be considered for the D2D communication shown in figure 2.5.

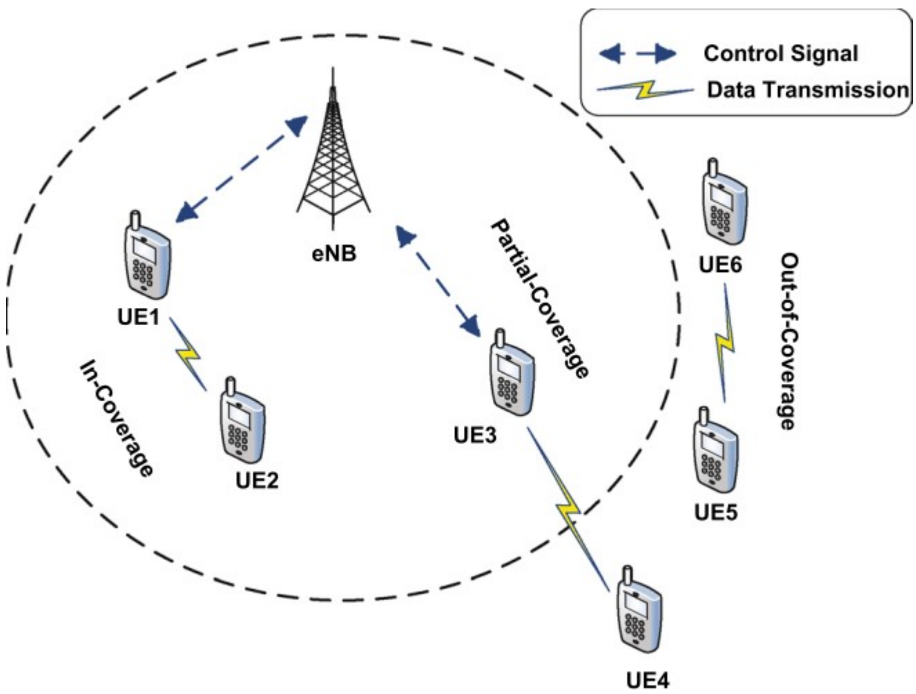


Figure 2.5: Coverage scenario for the D2D communication.

1. **In-coverage:** In this communication entire UEs or mobile users are in the coverage of the BS.

2. **Out-of-coverage:** In this communication, there are no UEs under the coverage of the BS.

3. **Partial coverage:**In this communication scenario, some of the UEs are not in coverage during the disaster, though some UEs are in coverage of the BS

or the core network. UEs inside the coverage area communicate with the BS. Those UEs not in the coverage of the eNB communicate with the other UEs inside coverage.

2.10.1 System Model and D2D Use Cases

Figure 2.6 shows the high-level architecture of the D2D communication under 5G, where UE can directly communicate with other UE in close proximity using the D2D communication link. UE such as mobile phones, personal computers, lap-tops, and IoT devices are connected via direct link use several RAT, which include the 3GPP evolution, Bluetooth or wifi standards[81]. V2X communication uses a dedicated 802.11p standard in the intelligent transport system (ITS) band [82]. Ship-to-shop communication integrated with the 5G satellite-terrestrial system establishes the connection with maritime communication [83].

The 5G core provides continuous service among the different satellite segments, RAT, maritime systems and terrestrial. This service also activates the data transmission by maintaining the QoS, ensuring that higher priority applications get the dedicated resources[84].

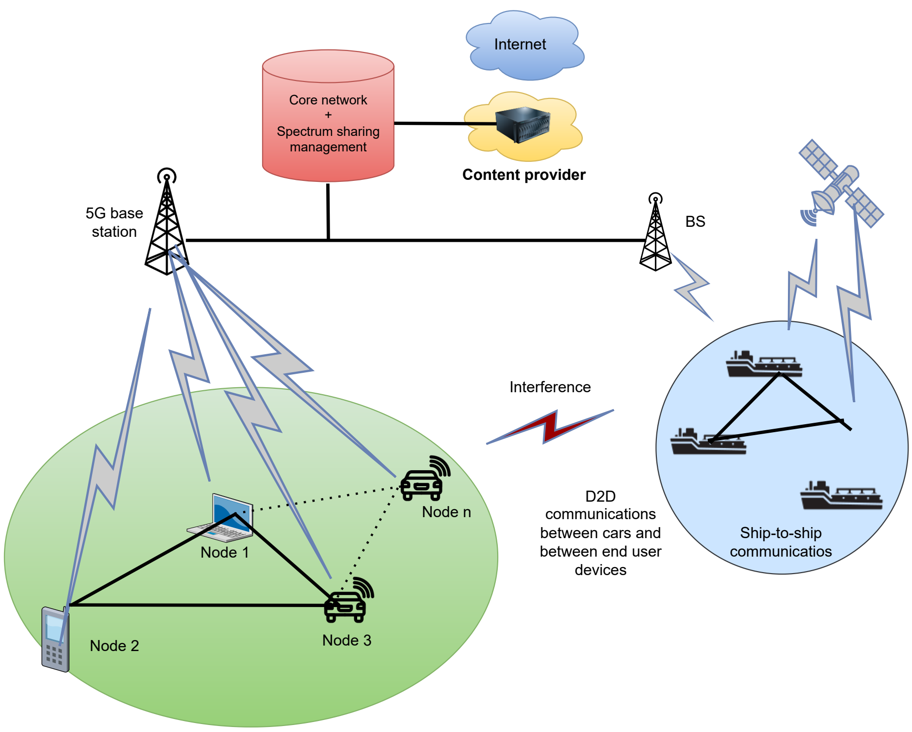


Figure 2.6: High level architecture of the D2D communication.

Table 2.4: Base station power consumption parameter. [86]

BS type	**Ntx**	P_{max} **(watt)**	P_0 **(watt)**	P_{Sleep} **(watt)**
Macro	6	39.8	4.7	75
Micro	6	6.3	2.6	39
Pico	2	0.13	4.0	4.3
Femto	2	0.05	4.8	2.9

2.10.2 Energy Model

In the wireless network, the BS consumes the highest percentage of energy/power. Supply energy consumption Esp for the single RF provide the relationship between transmission energy E_{tx} and supply energy [85].

$$E_{SP} = \begin{cases} E_o + \delta_E E_{Tx}, 0 < E_{Tx} < E_{max} \\ E_{Sl, E_{Tx}=0} \end{cases}$$

N_{tx} RF chain included when calculating the total energy consumption by the BS.

$Etotal = N_{tx} x E_{sp}$

The consumption model for the LTE user is calculated by the power consumption (mW) estimated during the receiving data in a connected state.

$E_{rx} = E_{on} + E_{rxBB} + E_{rxRF}(R_{rx}) + P_{rx}$

Where, E_{on}= cellular system active time energy consumption

P_{rx}= additional power consumption of the receiver being active

P_{rxRF}=RF block energy consumption

R_{rx}= Receiver power consumption

P_{rxBB}= Base band power consumption

Table 2.4 shows the summary of the measure parameter for the LTE based BS including macro, micro, Pico and femto.

2.10.3 D2D Use Cases

3GPP release 12 provides an essential feature for D2D communication, which is used in commercial, especially public safety, applications. As discussed above, group communication and proximity services are prominent features that open many doors for the use of many public safety applications, which makes disaster response system very successful. D2D communication can communicate 1:many and 1:1 communication. In 1:1 communication UE directly communicate with the other UE; however, in 1:many communication is a group cast or group communication services between UE. Both communications are valuable for disaster communication.

Prose Discovery:

Prose discovery system uses UE to discover other UE in close proximity. This discovery technique uses UMTS Terrestrial Radio Access Network (E-UTRAN)[87]. Both open and close discovery techniques are used for the prose discovery. In the open discovery, UE discovers another UE without authentication and authorisation. However, in close or restricted discovery, UE needs permission to initiate the discovery mechanism. These two are the same network-assisted prose discovery or without network-assisted discovery. The network-assisted discovery uses a core network-assisted Evolved packet core (EPC)[88]. This system, also known as EPC-Level Prose discovery as EPC control and inform the prose, enabling UE about the proximity.

On the other hand, D2D also has the capability to initiate discovery without the assistance of the core network. The discovery can be made autonomously when the UE lies outside network coverage. An innovative DRS can be developed by using this mechanism.

Switching between two different communication paths: This is one of the essential use cases for the disaster response application. Much traffic generates when any BS is damaged due to the disaster impact. In this case, the operator switches user traffic from the network infrastructure to the prose communication[89]. The proximity service is controlled dynamically by the operators.

Multiuser cooperative communication (MUCC): Users are classified into two different groups in this system. One user is known as a beneficial user group, and the other group is a supportive user group. In the benefited group, users are known to belong under the week signal[90]. On the other hand, supportive users belong under the strong signal. D2D communication is used between the benefited user and the supportive users. The overall result improves the quality of the signal. Figure-2.7 shows the MUCC communication in the D2D.

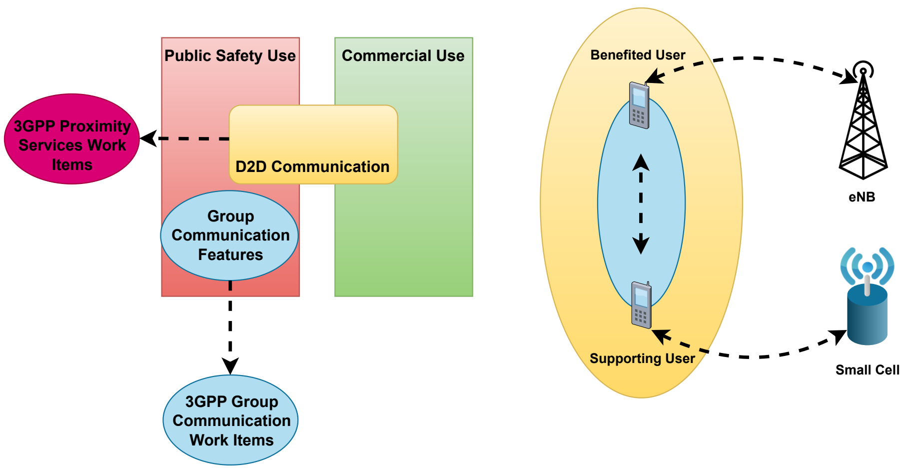


Figure 2.7: MUCC communication in the D2D.

D2D offloading: The overall network overhead can be minimised by using the facilities of data offloading provided by the D2D technology. In this technology, if any UE has a poor channel condition detected by the neighbour UEs in close proximity with the strong channel condition, D2D communication and data are relayed via cellular communication [91]. This will help to optimise downlink transmission overhead and minimise spectrum resources.

V2X communication: V2X under the 3GPP release 14 provides the supports for vehicle-to-vehicle (V2V), vehicle-to-network (V2N) communication, vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P) services. 3GPP release 15 included other extended features like automated and remote car driving. Both cellular and D2D communication have enhanced the services for V2X communication under the LTE-V services[92]. Collision avoidance, interference coordination and allocation of resources, deployment and traffic characteristics are different from traditional cellular communication and LTE-V service communication[93].

Security of data communication: D2D communication provides data security as, in this communication, data is stored and relayed from the trusted UE[94]. This technique can avoid accessing the untrusted insecure link to the database in the cloud.

Indoor positioning: 3GPP release 13 provides the indoor positioning service, which provides a higher accuracy level of indoor positioning and solves the multipath propagation problem[95]. It also helps for the critical voice service based on the ProSe D2D communication using the LTE device.

Enhancement of D2D relaying:3GPP release 15 enhances the network relay of the D2D communication, which also extends the coverage area. This also provides the facility to connect remote devices like sensors, wearable smart devices and other IoT devices. This relay provides good connectivity, extends and widens coverage and gets data from different sources, which is beneficial for the different sectors.

Maritime communication:LTE-Maritime is another crucial feature for the D2D communication use case release16, which includes developing the maritime communication system[96]. Both voice communication and data communication in different vessels are supported in this communication. It also covers the area of approx. 100 Km and provides continuous communication between the maritime radio communication with the 3GPP system.

2.10.4 D2D Discovery

Device discovery is an application layer procedure where specific messages are exchanged between two UEs. In this layer, UEs use PSDCH for device discovery. The device discovery can be classified into two categories which depend on the network involvement or not.

1. **Network-assisted discovery:** This network-assisted discovery is also known as EPC level discovery[97]. The BS of the existing network involves device discovery. The base station (BS) determines the proximity distance of UEs. The proximity UE originates and updates the location. As per figure xx, UE1 makes a proximity request. Prose function-1 requests to get the updated location for both UE1 and UE2 from the secure User Plane Location Platform (SLP)-1. Prose-1 function contacts the prose function2 to get the location and then creates a report about the location sent forward to the EPC. EPC then informs all other requesting devices about their proximity location and creates a proximity alert in the PC3 interface. The entire task involves analysing the UE's proximity location inside the network and notifying the interested users within the area. The EPC entirely controls the process, and the discovery process uses the parochial announcement of the UE. As a result, this process consumes more power to update the proximity location and exchange messages continuously. This EPC level discovery can be made only for the network coverage area in cases where the direct network discovery is absent.

2. **Direct discovery:**

   This discovery is beneficial for the disaster response system as this discovery process can initiate without network coverage. 3GPP release 12 introduces the direct discovery for both in and outside coverage scenarios.The process starts with the detection and identification of a UE with another close physical proximity UE. The process can be done via an E-UTRA radio signal[98]. There are two types of detection and identification depending on the secure application:

   Open discovery: No authorisation is required from the remote UE to detect, identify and communicate with the discoverer UE [99].

   Authorised discovery: for the detection, identification and communication with the remote UE, an explicit authorisation is required from the remote UE.

   There are two different discovery models used in this direct discovery. Model-X is considered the discoverer UE model, and Model-Y is remote UE. The corresponding message is also different in the process.

   Model-X: In this model, the discoverer UE broadcasts the discovery message "I am here". After sending this broadcast message, the UEs interested in discovering the nearest UE announce the required information. The other users are also given the proximity location and authorization (if required).

The interest UE monitor and processes the UE information. Figure 2.8 shows that this model-X supports open and authorised discovery.

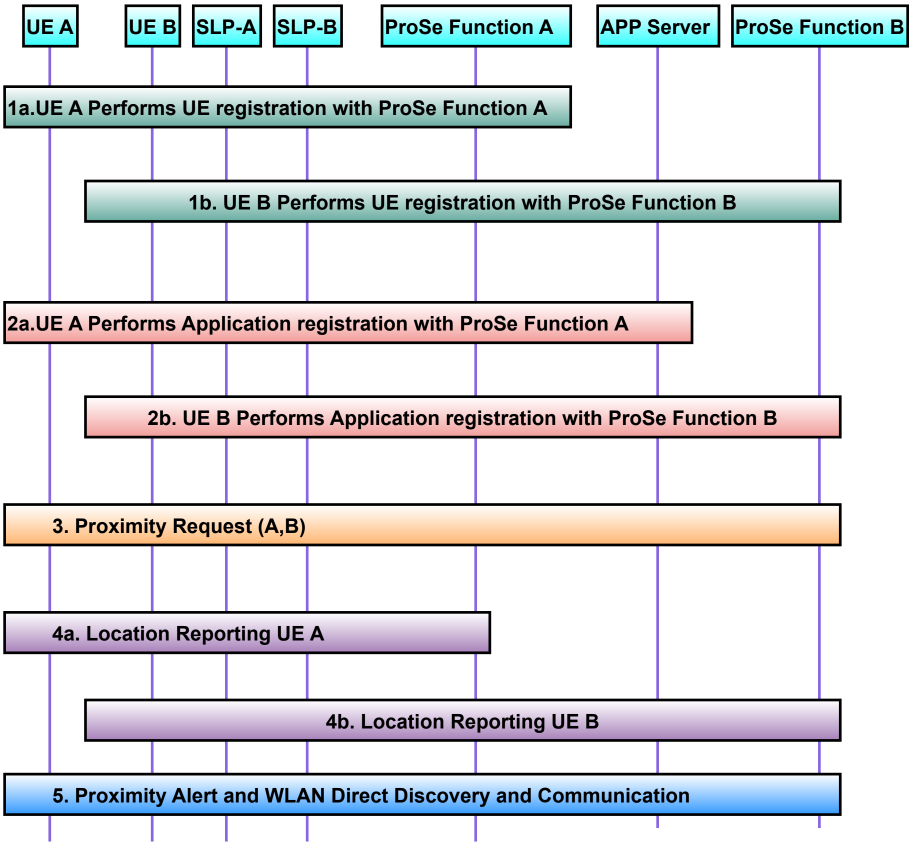


Figure 2.8: Open and authorised device discovery in D2D communication.

Model-Y in this model, is the UEs who want to discover broadcast messages("are you there or who is there or who are you etc.") with the required information for the discovery. The discoverer UE gets the relevant information and takes possible action to establish the communication. The information may or may not come direct from correspondence UE. This message can be relayed from another UE as well. Figure 2.9 shows the model Y for the device discovery in D2D communication.

Because of the discovery information packet size, the transmission and reception of the discovery packet in D2D communication are not simple. If the packet size is small, UE can transmit all the required sequences for the discovery information. This information is relatively less complex than the discoverer UEs. However, when the packet size is big and sends it periodically, it is challenging for the UE to analyse the information.

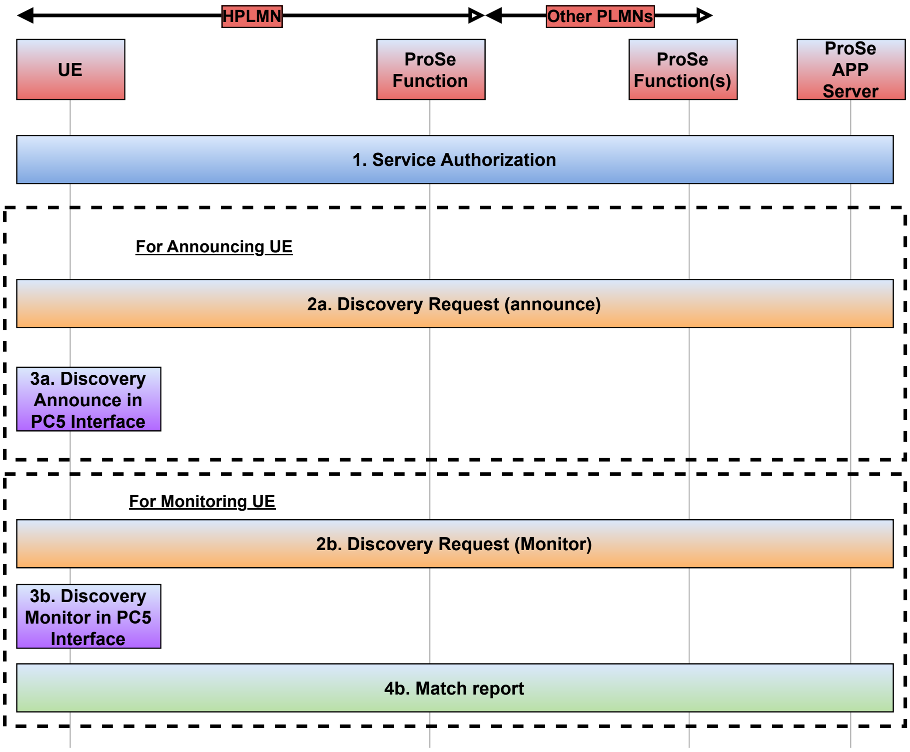


Figure 2.9: Model Y device discovery in D2D communication.

2.10.5 D2D Communication Mode

In D2D communication, mode selection is very important. Based on the spectrum resource utilization, the following communication mode, shown in figure-2.10 can be used in D2D communication.

Cellular Mode (CM) - In this mode, communication establishes as traditional cellular communication. Data from the DUE,s exchange through the evolved eNodeB. There are no facilities to direct communication and exchange data between two devices. This mode is very efficient when UEs have far distance between them or if D2D communication would not pay off.

Dedicated Mode (DM) -In this mode, some of the available resources are dedicated to D2D users for using the direct transmission. In DM, D2D transmission takes place only in one direction, either the DL or the UL. This mode of allocation is also known as overlay mode or an orthogonal mode. This is because the established communication between CUE and DUEs is assigned noncrossing/overlapping resources. There are some advantages of the dedicated mode when interference between cellular and D2D tier is not handled by the eNodeB. On the other hand, spectral efficiency is poor in this mode.

Shared mode (SM) - DU and CUEs use the same radio frequency resources in this mode. This mode is also known as underlay mode or non-orthogonal mode. In this mode, SM can use either DL or UL radio resources like the DM mode. In this mode, spectral efficiency is much better than the DM as a reuse factor of the radio resources is much higher in this mode. On the other hand, there are some disadvantages of SM mode, which is that higher interference might be produced between DUE and CUE. As a result, the complexity of the whole system is increased[100].

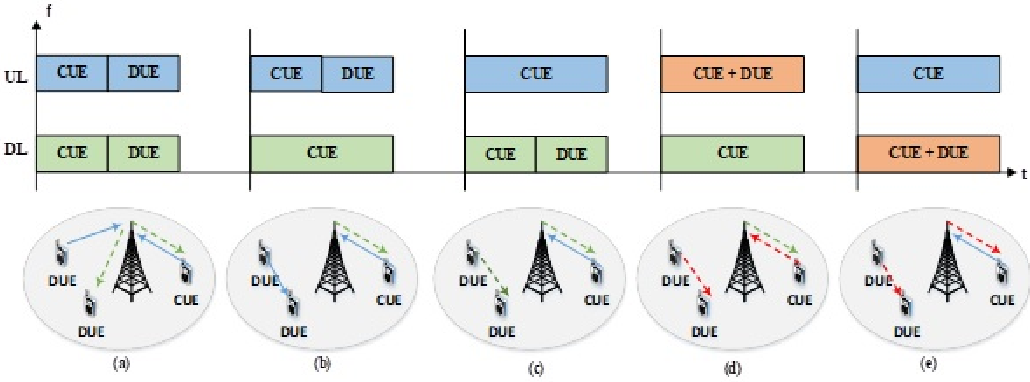


Figure 2.10: D2D communication mode. (a) CM. (b) DM(UL reused). (c) DM(DL reused). (d) SM (UL reused). (e) SM(DL reused).

2.10.6 Spectrum Utilization in D2D

Based on the spectrum resource utilization by D2D users, the D2D communication can also be categorized into two different categories, as shown in figure 2.11:

- In-band D2D
- Out-band D2D [101].

In band communication- In this communication UE under the cellular and D2D share the same spectrum band. This can be done by reusing the radio resources which underlay or by dedicated resources which is the overlay.

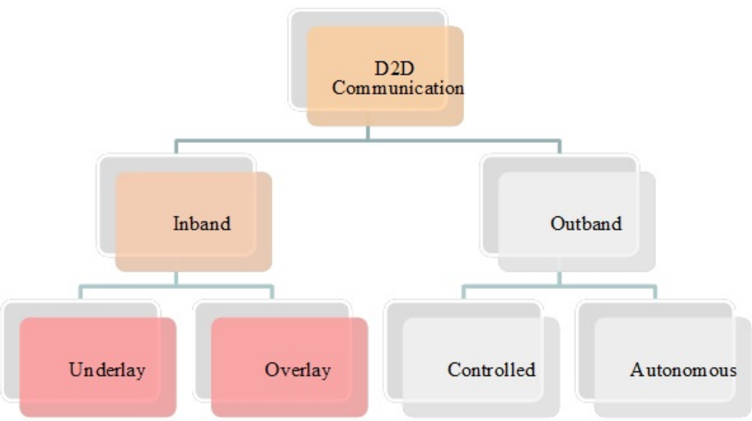


Figure 2.11: Spectrum utilization in D2D communications.

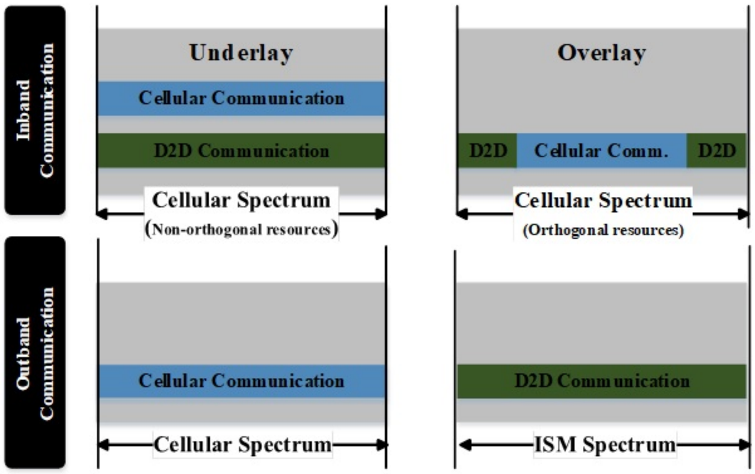


Figure 2.12: Inband and Outband D2D communication in cellular network.

The infrastructure is strongly controlled by the cellular network or cellular spectrum. This is the advantage of this network. On the other hand, it will introduce interference in the cellular network, which causes some extra overhead by requiring some extra computation procedure of resource allocation.

Out-band communication-In this communication industrial, scientific and medical radio bands (ISM) are used. These are the group of radio bands which are separate from the cellular radio spectrum. For this reason, no interference occurs between D2D and cellular network. As a result, UE in the D2D communication and cellular network can communicate seamlessly without any interruption.

The coordination between two different bands for achieving out-band D2D communication has many challenges. Based on the occurrence of the second interface (i.e. D2D communication interface), out-band D2D communication can be further divided into the controlled and autonomous modes. In the controlled mode, cellular network fully controls the D2D communication whereas in the autonomous mode the devices control it themselves. However, it is the irrepressible interference level of the unlicensed spectrum. As a result, providing the guarantee of the QoS is challenging in a highly saturated wireless area. Figure 2.12 shows the difference between in-band, out-band, underlay and overlay D2D communication.

Both in-band and out-band communication approach has some specific merits and demerits. The advantages of in-band D2D communications are:

1. Due to spatial diversity, spectral efficiency is very high in underlay D2D;
2. Each cellular device can use in-band D2D communication.
3. QoS management is easier as the BS can fully control the cellular spectrum.

However, the disadvantages of in-band D2D communications include:

1. In case of overlay D2D, cellular resources might be wasted due to allocating dedicated spectrum.

2. It is very difficult with interference management between D2D and cellular transmission within underlay.

3. High complexity resource allocation methods used for power control.

4. Simultaneous cellular and D2D transmission is not possible.

On the other hand, the advantages of out-band D2D communications are:

1. Zero interference between cellular and D2D users.

2. Like overlay in-band D2D, dedicated cellular resources are not required, an unlicensed ISM band will used.

3. Resource allocation is straightforward. This is because time, location and frequency of the user are not required by the scheduler.

4. Simultaneous D2D and cellular communication are possible.

However, out-band D2D has some disadvantages which are:

1. BS does not have any controlled of the interference of the unlicensed spectrum.

2. Out-band D2D communication only can use LTE and WiFi.

3. It is very important to manage power properly between two wireless devices. Otherwise, it might increase the device's power consumption.

4. As protocols used by different radio interfaces are not the same, they need to be encoded and decoded for the headers.

In summary, D2D communications in underlying cellular networks improve the performance of the cellular network. The performance parameter of the network is in terms of spectrum efficiency, energy efficiency, cellular coverage and other performance parameters.Table 2.5 shows the Inband and Outband performance of D2D communication.

Table 2.5: Comparative analysis of different types of D2D communications.

Criteria / Types of D2D communication	Inband		Outband	
	Underlay	Overlay	Controlled	Autonomous
Spectrum efficiency	Very high	Medium	Low	Low
Simultaneous D2D and cellular transmission	No	No	Yes	Yes
Required inter platform coordination	No	No	Yes	Yes
Energy efficiency	High	High	Low	Low
Required device more than one interface	No	No	Yes	Yes
Complexity to the scheduler	High	Medium	High	No

2.11 Data Security in D2D Communication

D2D communication involves direct communication between nearby devices, bypassing the need for an intermediate network infrastructure. As a result, data transmitted through D2D connections is vulnerable to various security threats. The primary data security issues associated with D2D communication are given below.

Eavesdropping is a significant security concern in the context of Device-to-Device (D2D) communication data security. It refers to the unauthorized interception and monitoring of data exchanges between two or more devices engaged in direct communication, without the knowledge or consent of the communicating parties. Eavesdropping can compromise the confidentiality of the data being transmitted and is a breach of privacy.

Device Authentication ensuring the authenticity of devices involved in D2D communication is essential. Robust device authentication mechanisms, including digital certificates and strong passwords, are required to prevent unauthorized access and impersonation.

Data Integrity is vital in D2D communication to prevent unauthorized or accidental data tampering. Any alteration of data can lead to miscommunication, data corruption, and potentially severe consequences, especially in critical applications. Maintaining data integrity is essential in D2D communication to ensure that the information sent from one device to another arrives exactly as intended, without unauthorized modifications.

Denial of Service (DoS) Attacks attacks are a significant threat to the security and availability of Device-to-Device (D2D) communication systems. A DoS attack aims to disrupt or completely disable the normal functioning of a network or service by overwhelming it with a flood of traffic, requests, or other malicious activities. In the context of D2D communication data security, DoS attacks can have serious consequences.

Man-in-the-Middle (MitM) attacks are a significant concern, where an attacker intercepts and potentially alters the communication between devices

To overcome the data security issues in D2D communication it needs to employ strong encryption and secure communication protocols to protect data in transit. In addition, cryptographic hashes need to be implemented to ensure data integrity during transmission. A robust device authentication mechanism needs to adopt for example digital certificates, for device identity verification. Moreover, it is required to measure the network traffic by limiting access control, and traffic filtering. Implementing Blockchain technology can solve the problem mention above.

Blockchain is a peer-to-peer (P2P) network that contains a chain of blocks.Each block contains a complete list of transaction records. Figure 2.13 illustrates a sample model of the blocks within the Blockchain framework.

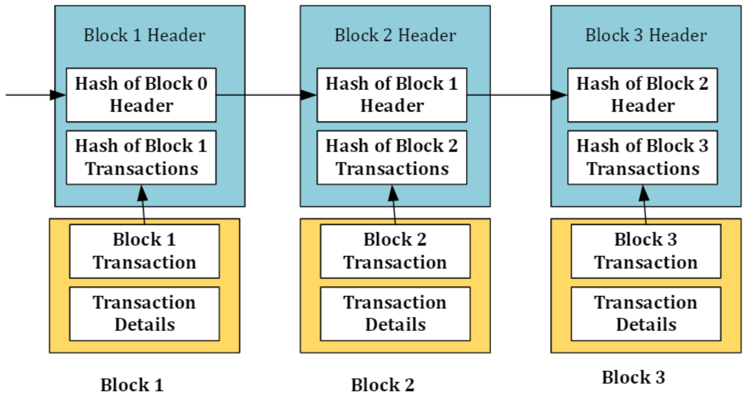


Figure 2.13: Blockchain architecture model.

A block in the Blockchain is maintained by cryptographic techniques such as hash function. The block header encompasses the block hashes [102]. Figure 2.14 shows the body of a block inside the Blockchain.

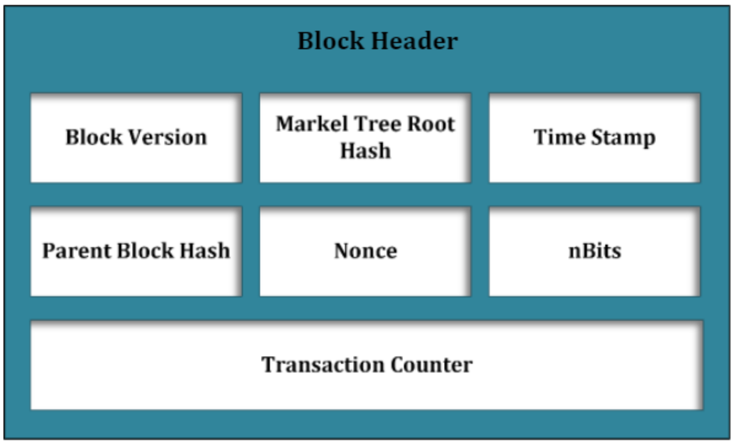


Figure 2.14: Blockchain architecture block.

The first block is called the parent block, also known as the genesis block. Each of the block headers consists of the six parameters:

Block version: This contains validation information which the block rule needs to follow this block.

Merkle tree root hash: This is the hash value of all the transactions stored inside the block. Timestamp:This contains the record of the transaction time in universal standard time format.

nBits: Validate the block hash by setting up the threshold value.

Nonce: This is a 4-byte field that calculates the hash value.

Parent block hash: This consists of a 256-bit hash value. It acts like a pointer, which is the point to the previous block.

The body of a block consists of the block header and several transactions. The maximum number of transactions of a block depends on the size of the transaction and block size. To secure and validate the transaction, an asymmetric cryptography algorithm is used [102]. Additionally, in an untrustworthy environment, a digital signature is used with the asymmetric cryptography algorithm. For the digital signature, both public keys and private keys are used for authentication, authorization, and validation.

The key characteristics of Blockchain given below:

Decentralized: Being decentralized is one of the key feature of Blockchain technology. It has a conventional transaction system, one of the central trusted agency needs to validate the transaction. As the Blockchain system does not need any authorized agency, it can directly access the web and store assets inside the Blockchain. It is also possible to store documents, contracts, or other digital assets directly over them using a private key [103].

Immutability: Any traditional database is a centralized system, which could be hacked at any time. However, Blockchain has the critical characteristics of immutability, keeping the ledgers in an infinite ending state of forwarding momentum.

Increased Capacity: Blockchain enhanced the total network capacity in comparison to the traditional centralized system. In Blockchain, all working together makes a more robust network comparing with some computers working as a centralized system.

Enhanced security: As Blockchain is a decentralized system and does not involve humans for the control of the system, it is more secure than the centralized system. It is also safe from any fraud and there is no risk of involvement by a third party. The system's transparency is very high and as it creates every user's unique profile in the block and every change inside the block is viewable.

CONSENSUS ALGORITHMS:

Consensus algorithm provides the Blockchain with a fully secured and verified network. The algorithm procedure via entire Blockchain network peers and reaches a common agreement in the current state of distributed ledger[104]. In these ways, consensus provides trust between the unknown peers in a distributed network.

POW: this is one of the common and popular consensus strategies in the cryptocurrencies application. If any node is required to publish a block of the transaction, each node in the network needs to calculate the block header's hash value [45]. The nonce inside the block header generates the different hash values. The algorithm then calculates the hash value threshold once one node gets the desired hash value distributed to the other nodes. All the nodes in the network mutually confirm the hash value to validate the block. The node that calculates the hash value is called miners and PoW is called mining in Bitcoin and other cryptocurrencies.

POS: POS has solved many disadvantages on the PoW Blockchain, such as energy consumption, scalability, and speed of transaction[104]. Ethereum originally designed the PoW, so transitioning to a PoS Blockchain, also known as Ethereum 2.0. PoS, uses the validators to validate the transaction, not miner and validators also known as nodes.

Byzantine Fault Tolerance (BFT):BFT is a tolerance system feature in a distributed network to get consensus when some nodes respond incorrectly or even fail to respond at all. In the decentralized distributed system, the nodes communicate with each other with no control, so there is a high chance that some unauthorized node is also participating. BFT measures the tolerance factor of those nodes, which provide incorrect information or no information.

Kafka- Kafka-Apache is open source used for the Hyperledger Fabric ordering mechanism. It is used for verification, providing high throughput and low latency. It can handle real-time data feed which is one of the key features that caught our attention to use Kafka.

RAFT- RAFT is a distributed consensus algorithm, which is used for an 'in case of failure' event. It solves the problem of event failure by using multiple servers to agree on a share state.

2.12 Data Analytics and Visualisation

A disaster response information system is a highly integrated and complex system that helps the first responder make a rescue plan more effective and efficient. It helps to gather accurate data from the disaster area and manage and analyse the disaster information promptly, which is a critical key for the success of DM[105]. DMS is divided into four parts:

1. Data collection and integration.
2. Data mining.
3. Visualisation.
4. Decision-making.

The data comes from the different data nodes whose data type is also different. Integrating this large unstructured data set, storing, securing and analysing in real-time make DMS more complex in terms of design and implementation.

As discussed above, DRS is divided into two phases with different requirements and varied functionalities;

1. Pre-Disaster management system.
2. Post-Disaster management system.

Both systems require accuracy and efficient decision-making with lower response time. Pre-disaster management system involves the prediction of the disaster, sending the notification about the disaster in the early warning system and situation awareness of the disaster. On the other hand, the post-disaster management systems involves a rescue plan, evacuation, response, rebuilding, and monitoring. A secure and efficient data source is crucial in both cases because both phases require analysis, prediction and decision-making depending on data accuracy[106].

It is also required to secure the information and extract the knowledge from the data for future system improvement. However, the DM framework is a complex application system that collects data from the heterogenous distributed data sources. Moreover, it is essential to use emerging tools and technology to enhance the performance of the DM in terms of availability, reliability, accuracy, maintainability and usability.

Big data analytics are very useful for natural disaster resilience. Data crumbs and advanced analytical capabilities make this technology into more powerful tools for a disaster response system. For disaster resilience, four analytical techniques are used:

Description analytics: : this involves describing the situation in a visualised format. This may include the statistical analysis of the damage to house/property, determining how many people need medical help or even could be how many Base Station (BS) or Sink damaged, or whether traffic volume has increased in detail after the disaster[107]. The data comes from social media and telecommunication companies annd may include the analysis of satellite imagery.

Predictive analytics: this analysis involves a decision-making interface where it is difficult to make a decision. This type of analysis involves a Machine Learning (ML) algorithm applied inside the Big data technology[108]. In addition, this analysis helps to determine how many factors/ features should be considered when making the decision. This analysis is more concerned with what will happen in the future. It includes early and accurate weather forecasting, movement of mobile phones, traffic congestion from call frequency, user mobility prediction, and also the ability to detect the possibilities of a sudden natural disaster.

Prescriptive analytics:this analysis involves justifying the future using different features or scenarios. It includes policy scenarios for the many different natural disaster strikes with different scales of impact. Successful disaster response system fully depends on how effective policy and procedure are, followed by the different scales of disaster impact[109]. It also helps to analyse and predict individual behaviour regarding mental and physical health risks and create a policy for the relief supply in different scales of disaster.

Discursive analytics: Discursive analytics helps to community enhance the awareness of the disaster impact and provides real-time feedback that helps to reduce the time for response and preparedness of the community[110].

Big data for prevention or mitigation: This technology helps the community to provide a disaster hazard map in case of volcanic eruptions or tsunamis. It also informs the community of the characteristics and vulnerability of the disaster. The analysis is also able to find mobile location and text patterns, which helps to understand how the disaster affected people's behaviour and response to the emergency. It will help responders to act accordingly, and enhances the efficiency of the disaster monitoring and prediction phase. For example, crowdsource hazard detection, mining social media content, aggregating data from the sensors and mobile phone motion detectors help the authority monitor and predict a disaster's effect. In addition, it also helps to make users aware of the effect of the disaster by sending a picture of volcanic activity.

Big data for Response and Recovery:: Response and recovery is one of the crucial phases of a disaster response system. Big data technology helps to accelerate the phase by analysing the data coming from different sources with a different format, for example, during a post-disaster situation when data is coming from different sensors, social media posts, text messages, voice calls, video calls, satellite and drone images[111][112][113][114]. These data formats are different from each other and need to process very quickly to better understand the impact of the disaster. Analysing the data helps to prioritise the workload for the first responders for the affected people, according to their requirements. Satellite and drone images help to understand infrastructure damage so that the authorities can make a better plan for the rebuild of the infrastructures. It also helps to identify the area and communication infrastructure that needs to be required urgently.

Big data in early warning: There is still a significant lag, in many undeveloped countries for data collection and analysis to predict the disaster and send an early warning to the individuals. This is often due to inadequate technological capabilities. The telecommunication system needs to be upgraded to get a real-time warning, especially for tsunamis, earthquakes, and floods. Effective disaster response system, accurate and valid channelling for data and use of the proper technology needs to adapt to detect early disaster warnings[115][116][117].

Big data in immediate effects: Different sources of data are very effective in assessing the disaster's effect. IoT and other remote sensors continuously monitor the disaster data and send them for analysis. There are three functions which can be beneficial for remote sensing.

1. Provide a map of the damaged area to enhance knowledge of the disaster's extent.

2. Measure damage to the infrastructure properly, which helps recovery and return to normal livelihoods.

3. Determine the effect on essential infrastructure, for example, communication infrastructure, water line, energy line etc.

To understand real-time impact and situation awareness a crowdsource approach is increasingly becoming popular. The increasing number of smart devices, satellite images, and drones make a crowd-based approach an effective method of collecting information, which can be analysed to get more accurate information about the effect of the disaster.

There are a number of projects to get situation awareness of a disaster impact. With the help of satellite image analyses, it is possible to determine post-hurricane or post-tsunami damage. In addition, high accuracy was achieved in detecting damage from the Haitian and Japanese earthquakes. A "Structure light" laser scanning device can generate a 3D map for the disaster area to analyse the extent of the disaster[118].

As the above system is open, decentralised big data technology can help integrate and mobilize all the data from different. This will help responders to make decisions and enable coordinated efforts of relief work. For example, during the Haiti earthquake, health workers spontaneously coordinated their activity via Twitter. Therefore an information platform is required to get the information and make decisions about people's needs. Big data can fill that requirement and help individuals get support promptly.

2.13 Data Collection and visualisation

Crowdsource data platform is another tool to collect information about a disaster' effects. All types of data, text, images and video are collected and stored in the crowdsourcing platform, which the people in the disaster areas upload. This will help with damage assessment. For example, in the Haiti earthquake, Gen-CAN established a company named ImageCat. This company collected images of about 1000Sq km that had been heavily damaged by the earthquake. The image included all kinds of structural damage in the area. The collection of imagery from the UAV is daily getting more popular as UAV is flexible and affordable to use. UAV-assisted aerial imagery is one of the latest technologies that is used to collect and analyse a disaster's effects and measure the damage. UAVs capture high quality and high resolution images and videos, compared with traditional sensor data. This also provides flexible data capture, acquisition and transfer. UAV used cloud storage which is more flexible for analysis purposes. The author[119] identified the damage caused to the building by the disaster. The author could count the total number of building collapses, including all the damaged features, such as buildings with damaged roofs, rubble piles, etc. This was done through the UAV raw imagery being converted to the 3D image in the cloud so that the expert could analyse and decide upon the damage. From this 3D viewpoint of the image, damage information can be predicted, which will help to get accurate information.

In the case of the super typhoon Haiyan in the Philippines, satellite image also made some disaster assessments, when satellite imagery was integrated with the open map technology to provide applications that showed the access path for the rescuer team[120]. The tweeter has also been used in some disaster response systems where data was collected through the tweeter and then big data technology was used to analyse the damage. China used this technique during Typhoon Haiyan. FEMA also developed a system where private and public agencies analyse tweets to find the location where aid and resources are required.

2.14 Disaster Management

After a mid- or large-scale disaster has happened, the traditional communication infrastructure becomes unresponsive due to the infrastructure being damaged partially or fully. As a result, a high volume of traffic is generated, which creates overloaded network congestions. With the advancement of wireless communication, there are several technologies that can be deployed rapidly, providing communication assistance for the response system[121]. Technology should offer scalable and efficient communication and be easy to deploy after any disaster.

This research contributes to establishing and integrating the latest technology to overcome the drawbacks of the DM network, which includes all of: infrastructure and hardware failure, network connectivity, energy deficiency, unpredictabilities, limited resources, system complexity, unorganised data, data security, privacy and other factors. The main cause of the above problem was full or partial damage to the communication network components like the Base Station [BS]. BS is in control of most parts of the communication; when it is damaged, it should be a self-healing functionality or be manually fixed immediately. However, sometimes immediate restoration is not possible due to the nature of the calamity. If the communication infrastructure is partially damaged, the functionality of the network decreases dynamically as the traffic load increases exponentially by the user. It will stop the services for both emergency communication and conventional networks. In addition, some places (hills areas, forests, or rural areas) have limited or insufficient Base stations or traditional communication infrastructures, like New Zealand and Nepal. After the earthquakes in Christchurch and Nepal, relief rescuers and volunteer teams from all over the world faced difficulties in relief and rescue. It happens because of the limited connectivity of the communication infrastructure.

For this communication, security and analytical problems, there must be an integration of all the factors, which will create a self-healing network infrastructure, providing security and validation of the data and creating a faster analytical process. This creates an intelligent disaster response system which will ensure the temporary network services collect and transmit validated and accurate data. It will also be a system where different valid data can be processed within a very short time.

2.15 Communication Challenges

To overcome the established communication network, data security, and data analytics obstacles caused by the natural calamity, TETRA and TEDS applications are proposed by the author[122] to overcome these problems. These applications would be used for relief operations using an alternative mission-critical communication system. However, the above technologies are not suitable for large-scale disasters or large emergency networks. In the aftermath of the calamity, there are technological limitations such as coverage, bandwidth, interoperability of end-to-end devices and data processing from the different format devices. Many researchers have proposed the deployment of a wireless network using big data technology which has self-configuration and self-healing capabilities [123] when the network is affected during a disaster. The author highlights the benefits of using big data technology; however, no solid evidence is provided.

This research has highlighted three areas where presented the contribution and proposed a smart, reliable, robust and efficient disaster response system. Figure 2.15 shows a holistic view of the contribution of this thesis.

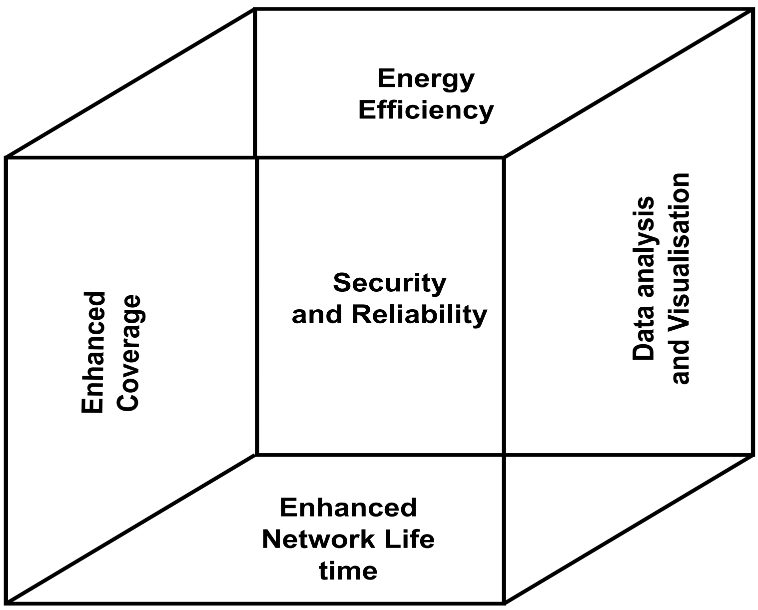


Figure 2.15: Holistic view of the thesis.

The emergency communication network can be categorised into two different types. One is infrastructure-based, and another is infrastructure-less. An infrastructure-based communication network assumes the network's existence after the disaster has occurred, which is an unrealistic prediction. The other type is more practical. The infrastructure-less network is flexible and able to restore the damaged network in adhoc style. However, just establishing communication is not the solution to the disaster response system. It must have secure, accurate data and must process this unstructured high volume of data quickly. The technologies used to provide the complete solution of DRS network discussed, for example, 3GPP-LTE, 5G network, Device to Device communication, clustering, multi-hop relay communication, device discovery, blockchain technology for security and Big data technology for data analysis, along with the existing literature. Figure 2.16 shows the overall DRS's existing problem and the approach to overcome the drawback of the problem presented in this research work.

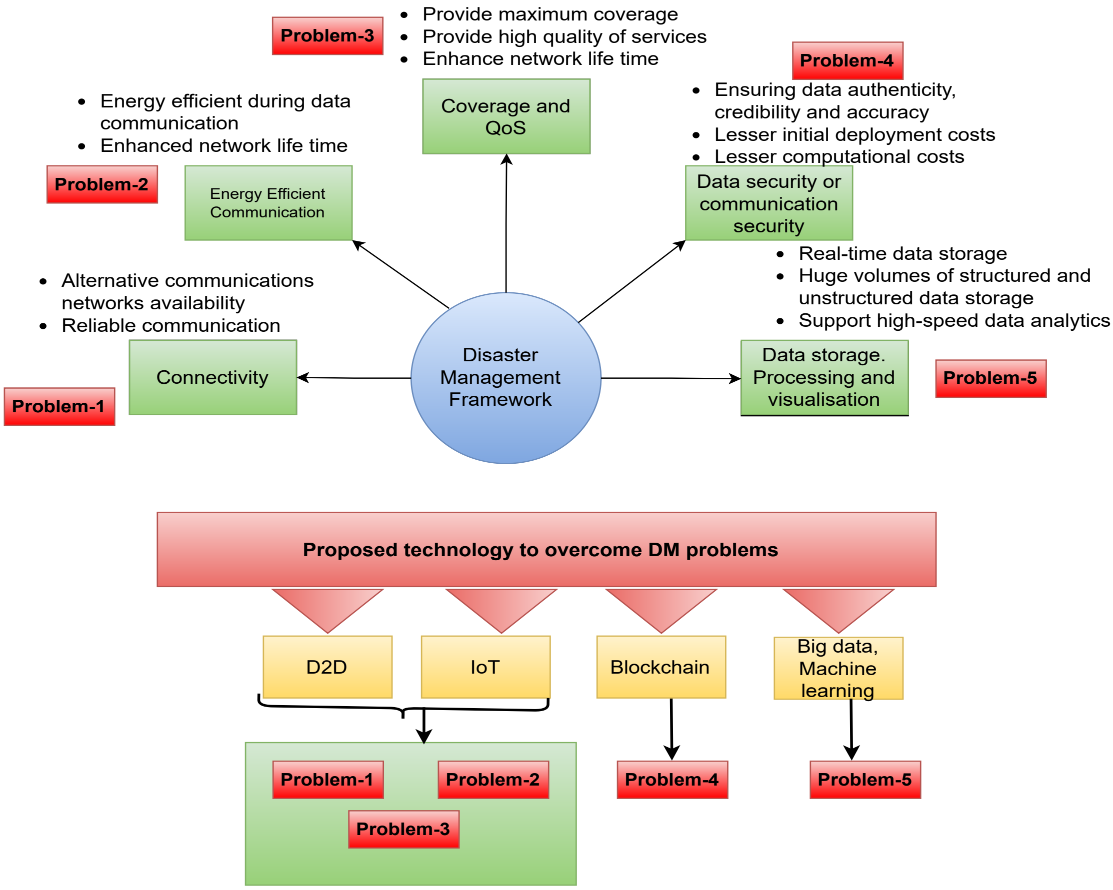


Figure 2.16: Problem of DM framework and proposed solutions.

2.16 Methodology

Research methodology helps to systematically resolve the research problem. It provides the direction of a research study on how the research will be completed scientifically, step by step. Research methodology depends on the nature of the problem, so the design of the methodology differs from problem to problem. Selecting a correct research methodology helps to understand a problem clearly and precisely so that research output can be evaluated accurately. For any research, the active selection of a suitable methodology is very important.

For this research study, Design Science Research Method (DSRM) is used. The main focus of this method is to solve definite challenges in order to get an adequate solution for the specific problem even if the solution is not the best. This method consists of six phases. Figure 2.17 shows the flow of the research method used in this thesis.

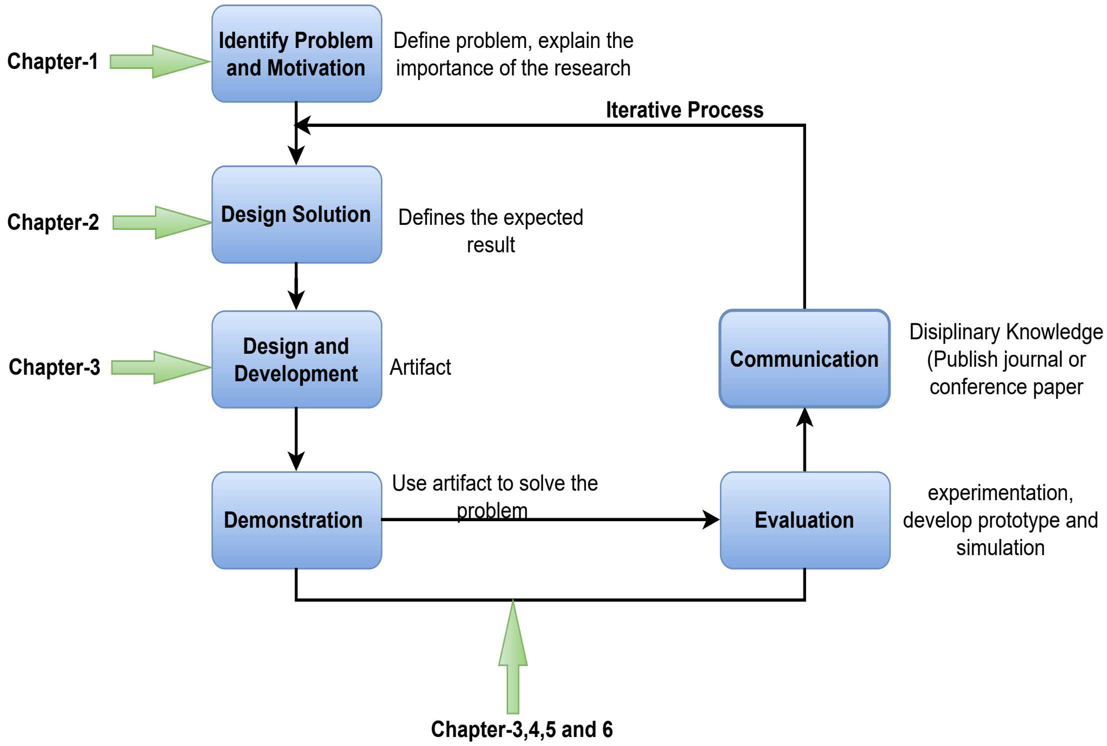


Figure 2.17: Research Methodology for the research.

First Phase:

This step is to identify the problem and define the points that motivate the researcher. During this phase, the researcher should justify the need of the research, validate the need, find its relevance and justify the importance of the problem, and the applicability of the proposed solution into real-life applications.

In this thesis, the problem statement is clearly defined as a disaster management framework. The justification of the research need is also illustrated from the previous literature. This phase is discussed in the chapter 1.

Second Phase . During the second phase of the research, the method is concentrated on the result of the problem.

In this stage, research defines the expected result for the problem. This thesis has clearly identified the expected result from the DM framework. In addition, the technological aspect, specification, integration and performance are analyzed and shown in Chapter 2.

Third Phase The third research activity is to design and develop a model of how to solve the problem. In the design and development step, the desired functionalities for the artifact, its proposed architecture, and its development need to be defined.

D2D, IoT, Blockchain and Big data technological integration for the DM network is clearly described in this thesis. Moreover, the parameters (energy efficient communication, QoS, extended coverage, enhanced network life time, security, data processing and visualisation), which are important for the DM network, are described and justified to validate the design model. Chapter 3 describes this phase of the thesis.

Fourth and Fifth Phase The fourth step is to use the artifact to solve the problem. This step can be done by experimentation, developing a prototype and simulation. The fifth research phase leads to evaluation. The researcher should analyse and summarise the characteristics of the artifact for solving the research problem.

These two phases are described and analysed in chapters 3, 4, 5 and 6. The theoretical model is explained mathematically. To validate the theoretical model, simulation is conducted in different technologies at different stages in the disaster management framework. The simulated result is then validated with the existing literature.

Sixth Phase The final step is the communication step which enables the researcher to communicate the problem and its relevance with others through scholarly journals or conferences.

These steps to fulfil this thesis were covered by publishing three journal papers and three conference papers. All three conference papers were accepted and the two journal papers are under a review process.

2.17 Summary

An emergency response system aims to safeguard affected areas and people to move into a safe evacuation from imminent danger by solving the problems of communications and management issues. Additionally, it provides vital safety support to other response operations and effectively manages all operations pertaining to disaster response. Furthermore, it encompasses the capability to mitigate the impact and consequences of any incident or catastrophe. In the unfortunate event of a disaster, it is imperative to ensure the continuity of the communication network recovery. In order for faster response during such calamitous situations, it is crucial to adopt emerging technology to exchange and utilization information. The technologies used to collect information and communication in emergency operations are an ongoing challenge that demands constant vigilance and attention. The revolution of emerging technologies help to the first responder to disaster-affected people. This chapter briefly, explains some of the technologies that can effectively use and enhance the performance for the disaster response system. The rest of the thesis chapter discussed how these technologies create diverse communication networks to enhance the response services for both victims and rescue teams.

Chapter 3

Cluster-Based Multi-Hop D2D Communication

3.1 Introduction

D2D communication through mobile devices can communicate with other mobile devices without any help from a Base Station (BS). In addition, it does not depend on core switching for routing the traffic. This independent communication feature is one of the key values for emergency communication when infrastructure is damaged by natural or man-made disasters. Moreover, cluster-based multi-hop communication not only provides the communication connection to the disaster affected people but also has the capacity to increase its coverage area. In this chapter,cluster-based D2D communication in 5G's performance is analysed, simulated and quantified when the existing infrastructure fails because of the disaster. A novel analytical method that can analyse the performance of the clustering-based D2D communication. The analytical parameters are based on the outage probability and energy, which are very important matrices for any emergency communication network.

3.2 Background of The Chapter

Traditional cellular networks use direct single-hop communication between the mobile user (user node/UE) and the BS. This connection is beneficial in reducing the delay in communication and providing quality of service (QoS). However, it causes a problem of high-volume data or voice traffic load as it has limited spectrum resources. As a result, the outage probability increases, and network coverage decreases, especially in emergencies. Handling this high volume of data traffic requires increasing the network capacity.

D2D under 5G can play a significant role in the emergency communication network in case of vulnerable network, traffic or network congestion, or enhancing the network capacity[124]. Because of the low cost and the capability to handle a high volume of data, D2D is becoming more popular for public safety networks, because many studies have been done to reduce end-to-end delay and energy consumption and enhance the coverage area in the emergency communication network[125].

However, D2D services performance (QoS) in different disaster scales and interference management still have some problems for the standardisation of multi-hop D2D communication. The primary focus of this chapter is to investigate D2D performance in the emergency network on a different scale of disaster effect on the communication network. A mathematical model has been derived and simulated to justify the outage probability and network coverage result. A simulation result shows the outage probabilities with the varying SINR for the different disaster impacts in the network.

3.3 System Model

In this chapter, D2D communication-based disaster response framework is proposed. The framework efficiency is analysed in terms of coverage probability, network capacity, energy efficiency and overall system performance, with different scales of the disaster damage on the network area size. The system model is shown in figure 3.1.

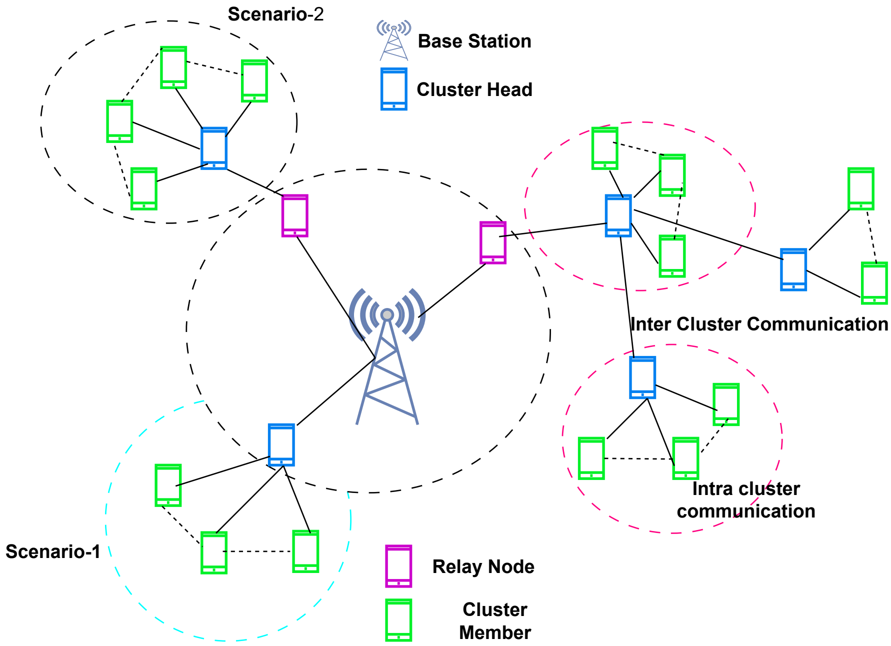


Figure 3.1: System model of a disaster network.

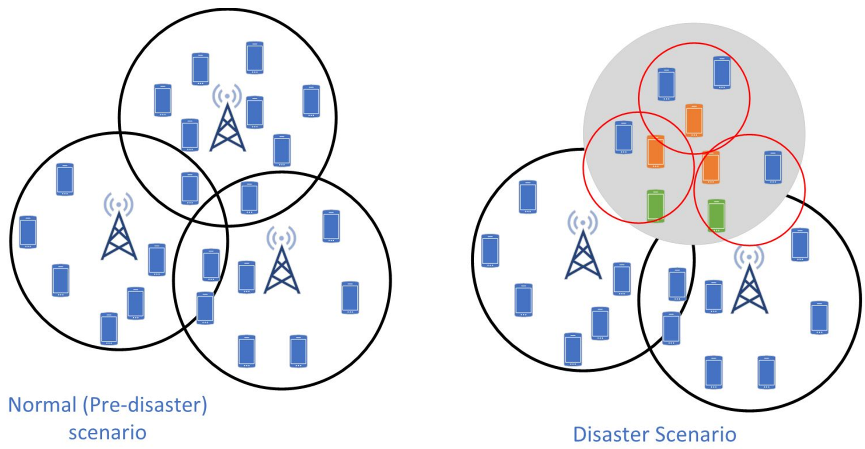


Figure 3.2: Overview of the network (**a**) Normal / Pre Disaster scenario (**b**)Disaster scenario.

In this model,a heterogeneous cellular network is considered which consists of L tiers. It assumed that the distribution of base station in a tier follows a homogeneous poisson point process (PPP) ϕ_{BS} with spatial density λ_{BS}. The UEs in the network are also considered as a homogeneous PPP ϕ_{UE} with spatial density λ_{UE}. In the aftermath of a disaster it is practical to consider that some of the BS may fail to provide services. In this situation, the UEs under the failed BS will form a cluster and establish D2D communication. All the communication inside the cluster will be through cluster heads. Figure-3.2 shows the normal network scenario and after disaster network scenario. The gray colour indicates the disaster area where there is no BS.

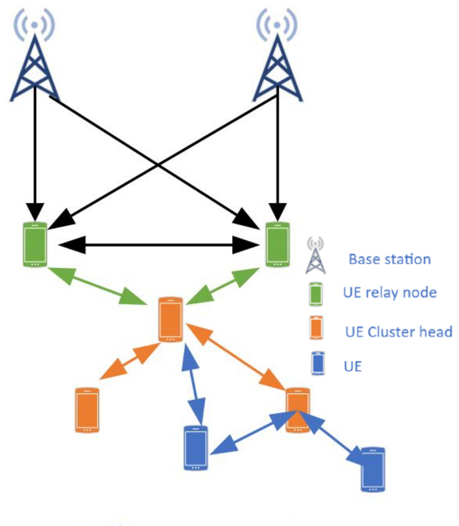


Figure 3.3: Analytical model of a disaster network.

Symbol	Description
L	Number of tier
$_{BS}$	Distribution of BS
λ_{BS}	Spatial density of of BS
λ_{UE}	Spatial density of UE
$h_{BS.R}$	channel between BS and Relay Node
$h_{R.CH}$	Channel between Relay and CH
h_{CH-CH}	Channel between CH to CH
P_{BS}	Transmission power of BS
P_R	Transmission power of Relay node
P_{CH}	Transmission power of CH
τ_{th}	SINR threshold for successful communication
P_{Ri}	Power received at relay R_i
P_{BS_i}	Power transmitted by BS_i
γ_{Ri}	SINR at Relay R_i
ψ_i	set of BS occupying the same frequency
ψ_R	set of relay node
ψ_{CH}	set of Cluster Head
I_R	Interference from RNs
I_{CH}	Interference from CH
I_D	Interference from D2D
α	Pathloss component
$P_{out(BS-R)}$	Outage Probability at UER
$P_{out(R-CH)}$	Outage probability at CH
$P_{out(CH-CH)}$	Outage probability at D2D

It has been considered that D2D communication will be through CH to CH. It also assumed that there is at least one UE from each functional BS to serve a relay node with the cluster head in the disaster area. The outage probability of a link is the probability that SINR of the link falls below a predefined threshold level(τ_{th}). $\tau_{th}$is considered as a known parameter.

Figure 3.3 shows the analytical system considered for the disaster scenario.At first, the outage probability calculated of the link between BS to UE relay(UER) device with relay and UER being used interchangeably. It has considered the small scale fading channel condition between BS and UER which is denoted by the $h_{BS.R}$. Therefore the received power at the relay node can be written as:

$$P_{BS_i.R} = P_{BSi} h_{BS_i.R} D_{BS_i.R}^{-\alpha} \tag{3.1}$$

Where,$D_{BS-i.R}$ is the distance between BS at the i^{th} tier and the relay node and α

is the pathloss component. Hence the signal to noise ratio (SINR) at R_i is expressed as follows:

$$\gamma_{Ri} = \frac{P_{BSi} h_{BS_i.R} D_{BS_i.R}^{-\alpha}}{I_R^{(i)} + n_{Ri}} \tag{3.2}$$

Where, n_{Ri} is the thermal noise which is usually a negligible component of interference in a dense network. I_{Ri} denotes the received interference at relay R_i. Here equation 3.2 becomes

$$\gamma_{Ri} = \frac{P_{BSi} h_{BS_i.R} D_{BS_i.R}^{-\alpha}}{I_R^{(i)}} \tag{3.3}$$

The overall interference at R_i is the sum of all the BS's transmission from different tiers occupying the same frequency at a given time slot as well as the interference from the cluster head. Hence

$$\mathrm{I}_{CH_i} = \sum_{i=1}^{L} \sum_{Z \in \psi_R} P_{R_j} h_{R_j.CH_i} D_{R_j.CH_i}^{-\alpha} + \sum_{CH_j \in \psi CH} P_{CH_j} h_{CH_j.CH_i} D_{CH_j.CH_i}^{-\alpha} \tag{3.4}$$

Now for the UE relay to CH hop, the received power at CH_i can be expressed as follows:

$$P_{R.CH_i} = P_{Ri} h_{R_i.CH_i} D_{R_i.CH_i}^{-\alpha} \tag{3.5}$$

the SINR at CH_i is:

$$\gamma_{CHi} = \frac{P_{Ri} h_{R_i.CH_i} D_{R_i.CH}^{-\alpha}}{I_{CH}^{(i)}} \tag{3.6}$$

Where I_{CHi} is the overall interference at CH_i i.e. interference from other relays and the cluster heads.

$$I_{CH_i} = \sum_{Rj \in \psi_R} P_{Rj} h_{R_j.CH_i} D_{R_j.CH_i}^{-\alpha} + , \sum_{CH_j \in \psi_{CH}} P_{CHj} h_{CH_j.CH_i} D_{CH_j.CH_i}^{-\alpha} + \sum_{Dj \in \psi_D} P_{Dj} h_{CH_j.D_j} D_{j.CH_i}^{-\alpha} \tag{3.7}$$

In case of the CH to CH D2D communication which is shown as orange link in Figure-3.3 the received power at CH is:

$$P_{CH(D2D}) = P_{CHi}h_{CH_j.CH_i}D^{-\alpha}_{CH_j.CH_i}$$

(3.8)

and the SINR at CH_j is:

$$\gamma_{CH_(D2D)} = \frac{P_{CHi}h_{CH_j.CH_i}D^{-\alpha}_{CH_j.CH_i}}{I_{CH}{}^{(i)}_{D2D}} \tag{3.9}$$

The $I_{CH(}D2D)$ is the overall interference from the CH and the neighbour UEs. Hence

$$I_{CH_(D2D)} = \sum_{CH_j \in \psi_{CH}} P_{CHj}h_{CH_j.CH_i}D^{-\alpha}_{CH_j.CH_i}$$

$$+ \sum_{D_j \in \psi_{CH}} P_{Dj}h_{CH_j.D_i}D^{-\alpha}_{CH_j.D_j}$$

(3.10)

The outage probability is calculated for each link which are BS to UR relay, UE relay to CH and CH to CH. The overall outage probability of the network is the scalar product of the individual outage probabilities. Hence

$$P^{Overall}_{out} = P_{out(BS-R)}P_{out(R-CH)}P_{out(CH-CH)} \tag{3.11}$$

The outage probability of the link between BS_i and relay can be expressed as:

$$\begin{aligned} P_{out(BS-R)} &\cong 1 - P(SINR \geq \tau_R) \\ &\cong 1 - (\frac{P_{BSi}h_{BS_i.R}D^{-\alpha}_{BS_i.R}}{I^{(i)}_R} \geq \tau_R) \\ &\cong 1 - (h_{BS_i.R} \geq \tau_R P^{-1}_{BS_i} D^{\alpha}_{BS_i.R} I_{Ri}) \\ \cong 1 - \int_0^\infty & P(h_{BS.R_i} \geq \tau_R P^{-1}_{BS_i} D_{BS_i R}) f I_{Ri}(s) ds \\ &\cong 1 - \int_0^\infty K^c_{R_i}(\tau_R P^{-1}_{BS_i} D_{BS_i R}) f I_{Ri}(s) ds \end{aligned} \tag{3.12}$$

It is considered, the interfering relay's density γ_R around R_i the outage probability can be expressed as follows[126]:

$$P_{out(BS-R)} \cong 1 - \sum_{i=0}^{N_{Ri}-1} \left[\frac{-s}{(i!)} \frac{d^i}{ds^i} \xi I_{Ri}(S) \right]_{s=\tau_R P_{BS_i}^{-1} D_{BS_i R}} \tag{3.13}$$

The outage probability of the link between Relay and CH can be expressed as [127]:

$$\begin{aligned} P_{out(R-CH)} &\cong 1 - P(SINR \geq \tau_{CH}) \\ &\cong 1 - (\frac{P_{Ri} h_{R_i.CH} D_{R_i.CH}^{-\alpha}}{I_{CH}^{(i)}} \geq \tau_{CH}) \\ &\cong 1 - (h_{CH_i.CH} \geq \tau_{CH} P_{CH_i}^{-1} D_{CH_i.CH}^{\alpha} I_{CHi}) \\ &\cong 1 - \int_0^\infty P(h_{CH.CH_i} \geq \tau_{CH} P_{CH_i}^{-1} D_{CH_i CH}) f I_{CHi}(s) ds \\ &\cong 1 - \int_0^\infty K_{CH_i}^c (\tau_{CH} P_{CH_i}^{-1} D_{CH_i CH}) f I_{CHi}(s) ds \end{aligned} \tag{3.14}$$

The interfering density $\gamma_C H$ around CH_i, the outage probability can be expressed as follows:

$$P_{out(R-CH)} \cong 1 - \sum_{i=0}^{N_{CHi}-1} \left[\frac{-s}{(i!)} \frac{d^i}{ds^i} \xi I_{CHi}(S) \right]_{s=\tau_{CH} P_{R_i}^{-1} D_{R_i CH}} \tag{3.15}$$

The outage probability of the link between CH and CH can be expressed as:

$$\begin{aligned} P_{out(CH-CH)} &\cong 1 - P(SINR \geq \tau_{CH}) \\ &\cong 1 - (\frac{P_{CHi} h_{CH_i.CH} D_{CH_i.CH}^{-\alpha}}{I_{CH}^{(i)}} \geq \tau_{CH}) \\ &\cong 1 - (h_{CH_i.CH} \geq \tau_{CH} P_{CH_i}^{-1} D_{CH_i.CH}^{\alpha} I_{CHi}) \\ &\cong 1 - \int_0^\infty P(h_{CH.CH_i} \geq \tau_{CH} P_{CH_i}^{-1} D_{CH_i CH}) f I_{CHi}(s) ds \\ &\cong 1 - \int_0^\infty K_{CH_i}^c (\tau_{CH} P_{CH_i}^{-1} D_{CH_i CH}) f I_{CHi}(s) ds \end{aligned} \tag{3.16}$$

The interfering density γ_D around D_i, the outage probability can be expressed as follows:

$$P_{out(CH-CH)} \cong\cong 1 - \sum_{i=0}^{N_{CHi}-1} \left[\frac{-s}{(i!)} \frac{d^i}{ds^i} \xi I_{CHi}(S) \right]_{s=\tau_{CH} P_{CH_i}^{-1} D_{CH_i CH}} \tag{3.17}$$

3.4 Cluster Head Selection

In a disaster network, energy is one of the critical parameters to enhance the network's lifetime. As a result, energy-efficient communication is very crucial for disaster communication. The disaster network is divided into two regions, one being the non-disaster region, where UE is connected with the BS, and the other being the disaster region, where there is no BS for the UE. For this region, UE will form the cluster to communicate with the BS. In a cluster, there is one Cluster Head (CH) responsible for collecting the data from other cluster members and transmitting it. CH selection depends on the number of parameters, e.g. residual energy, distance from the BS, channel condition, etc. In our model figure 3.2 (b), a clustering algorithm based on the residual energy of the node is used and the distance from the BS. The node with higher residual energy in the disaster area has a better chance of becoming the CH.

Let us consider that N number of nodes randomly distributed in the disaster area W x W and the initial energy is distributed non-uniformly among the nodes. For the cluster selection, a distributed algorithm used, where nodes make autonomous decisions without any centralized control. The procedure of CH selection is calculated by the threshold value T_{CH}. All the nodes selected in the region generate a random number between zero and one M($0 \leq$ M < 1). If the random number is satisfied with M $\geq T_{CH}$, the node is elected as the head node of the cluster for the current round. The threshold value T_{CH} is calculated as follows[128]:

$$T_{CH} = \begin{cases} \dfrac{P_{CH}}{1 - P_{CH} * (rmod(\frac{1}{P_{CH}})) * D}, N \in G \end{cases} \tag{3.18}$$

Where, P_{CH} is the probability of the node is selected CH based on the residual energy. r is the current number of round, Gi is a set of nodes that were not selected as a cluster head in the last rounds, mod(·) denotes the modulus operator and D denotes the distance from the BS. P_{CH} can be defined as:

$$P_{CH} = P_{opt} \frac{E_i}{E_{avg}} \tag{3.19}$$

where P_{opt} is the optimal probability. E_i is the ith node residual energy and E_{avg} is the average energy of the network.
The average energy of the network at round r is denoted by:

$$p_{avg} = \frac{1}{N} \sum_{i=1}^{N} E_i(r) \tag{3.20}$$

P_{opt} can be obtained by $P_{opt} = \frac{P}{N}$ where P is the predetermined number of CH which

is most of the case 10% of the total number [129].
When the node is selected as CH using the threshold equation, the CHs must let the other nodes know that they have been selected for the CH for this round.

From the beginning of the clustering phase, all the UEs broadcast the beacon, which has a battery label above the threshold P_{th}. Peer discovery resource is used for the beacon broadcast. The entire beacon signal consists of battery information, mobility information, and distance from the BS information. When the UE receive a beacon signal from the other UE, it calculates the SINR value. When the SINR value is below the threshold SINR value, UE can understand it is far from other UE. This UE select itself as a CH.

Algorithm 1 CH and Cluster member selection algorithm

```
Broadcast the beacon
N=Total no of UE
D=D_1, D_2, D_3, ...., D_N relative distance
M ∈ {1, 2, 3, ....N_M}=Mobility of UE
γ_th= SINR threshold
for i ∈ {1, 2, 3, ...., N} do
    if γ_{i,n} > γ_th then
        N_i ← CH
    elseγ_{i,n} < γ_th
        N_i ← ClusterMember
        if D_{i,n} > D_{i+1,n} then
            N_{i+1} ← CH
        elseD_{i,n} == D_{i+1,n}
            if M_(i, n) > M_(i + 1, n) then
                N_i ← CH
```

If the beacon signal is above the threshold value, then the UE decode this beacon signal. This signal can be received from the outside coverage UEout. When UEout receives the signal, it replies with a paging signal. This determines the total number of devices outside the coverage and the distance from the BS. It will also help calculate the number of hops required to transmit the data. When the UE receives a paging signal from the UEout, it broadcasts the beacon again to give information about the total number of devices outside the coverage area. UEout determines and compares the battery life among the devices. The devices that have higher battery lives select themselves as CH. In addition, mobility is also considered to select the CH when two or more devices have the same battery life. When both mobility and battery life are the same, then it considers the distance and hop required to send data to the BS are considered.

The CHs beacon broadcasts an advertisement message (AVD) to let all other nodes in the network know about CH position. The broadcast message consists of node ID and a header. Each of the member nodes chooses the desired CH for the current round that requires less energy for the communication. This can be determined by the strength of the received signal from the advertisement message of CHs. A random CH will be selected in case of equal strength of the received signals. When the node decides the desired CH, the node must inform the CH that the node will be the member of that cluster. The node transmits a join-request message to the CH which consists of node ID and CH ID.

3.5 Simulation Results

In this section, the simulation results are presented to analyse the disaster model discussed above. The analytical result shows the availability of the network in different scales after the disaster has struck. The model is simulated to find the outage probability by varying the different values of SINR threshold. This result will help to determine what services to employ when there will be infrastructural damage due to the disaster. The results also calculate the coverage and energy efficiency of the use of cluster-based D2D communication during the emergency communication. The simulation parameters and the values used for the simulation are listed in Table 3.1 Monte Carlo simulation has been used to analyse the disaster model and validate the result.

Table 3.1: List of simulation parameter.

Parameters	values
Simulation Software	Matlab 2019a
Network Deployment	PPP
Cell Size	25KM^2
Number of users	variable
Pathloss exponent	4
Number of UER	25
Cluster size	variable
Cluster number	variable
Cell Radius	1KM
Iteration	10000
SINR Threshold	0-30dB

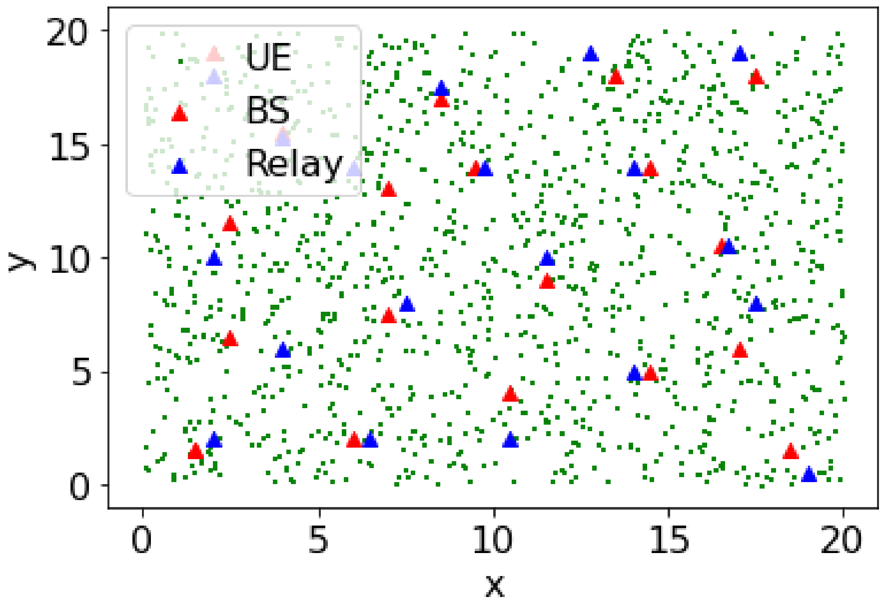


Figure 3.4: Simulation network: Node distribution using PPP.

There are two autonomous PPP used in this simulation. One is UER, also known as cellular users, that is used for the relay node; the other is CHi, which is used for the D2D users. Figure 3.4 shows the simulation network model 20X 20 square KM. The red triangles are the BS and cyan plus are UE-Relays connected with the respective service stations (either BS/ Micro Cell/PicoCell) inside the same tier. CHi is connected to the UER. As mentioned before, the communication link between UER to CH and CH to CH are considered D2D communication. CH are connected with the nearby UER and a device inside the cluster connected with the CH. According to the theoretical model, homogenous PPP with special density of the users is used. BSs are connected with the UER and all other users are connected with the BS in normal mode. In the absence of a BS, when the users would not be able to connect with it, they will form the cluster and all the communication will be done via CH. The performance in different disaster impacts calculates that cause the infrastructure damage (10%, 20%, 50% and 70%). It assume that 10% of the disaster impact by means of 10% of BS damaged due to disaster from the total number of BS deployed; 20% disaster impact means 20% BS absence and so on. Figure 3.5 shows SNIR vs Outage probability for different disaster effect 5 KM area. It also assumed that 10% disaster in 5KM area means 1 BS damage, 20% damage means 2 BS damage, 50% damage means 3BS damage and 70% damage means 4BS damage. Figure 3.5 shows that up to three BS damage does not made significant difference between outage probabilities. However, more than 40% outage probability occurs for 4BS damage.

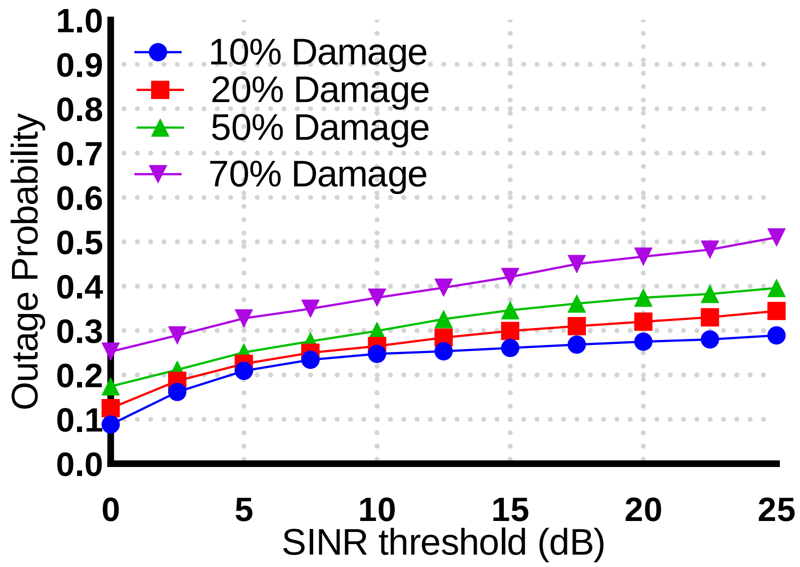


Figure 3.5: SINR vs Outage probability for different disaster effects (5KM area).

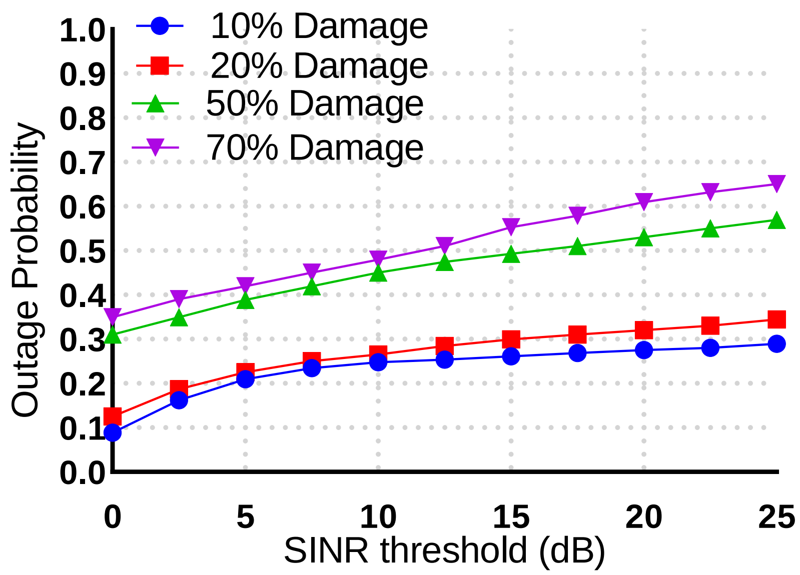


Figure 3.6: SINR vs Outage probability for different disaster effects (10 KM area).

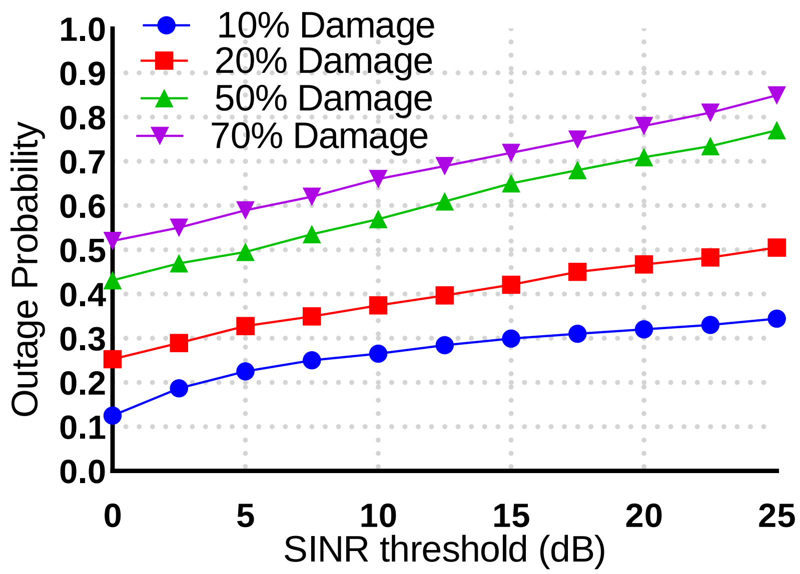


Figure 3.7: SINR vs Outage probability for different disaster effects (20 KM area).

Figure 3.6,3.7 shows the outage probability of the D2D user with respect to the SINR threshold. The result compares the QoS for the different scales of disaster impact. For the simulation, it was assumed that 10% disaster damage in 10 KM means 1 BS damage, 20% damage means 2BS damage and so on. When considering the 20 KM area, 10% damage means 2 BS, 20% damage means 4 BS and 70% damage means 14 BS damage out of 20 BS. The SINR threshold is also defined as the required minimum signal to identify the transmitted signal. It has been observed that outage probability increases with the increase of SINR. This is because the channel fading distribution is in exponential form and for the interference signal (IR, I_{CH}, $I_{CH(D2D)}$). When the disaster effect is 10% within 1KM, the outage probability of the D2D users is almost negligible. However, with the increase of KM (5KM, 10KM, 20KM) the outage probability will start increasing as it will increase the interference, channel fading, link outage and channel congestion. In addition, increasing with the impact of disaster (10%, 20%, 50%, 70%), the outage probability increases but not in an exponential way. Because the multiple tiers of the network can handle the interference, this reduces the channel fading. According to equation 3.17, channel quality is an important factor for the outage probability of the D2D users. For the D2D user, the outage probability also depends on the distance from the relay node. That is why in figure 3.5, (within 5 km area) there is no significant outage probability. However, with the increase of disaster scale and distance, the outage probability also increases because it requires multiple hop to extend the coverage. In addition, there are also possibility of having channel fading, broken channel and interference from different CH and nodes. All the D2D users are getting highest possible threshold SINR. The outage probability is below 50% for the SINR threshold of 5dB in case of any disaster effect except 70% damage in 20 KM. The lowest threshold of SINR provides the lower outage probability in the emergency communication network.

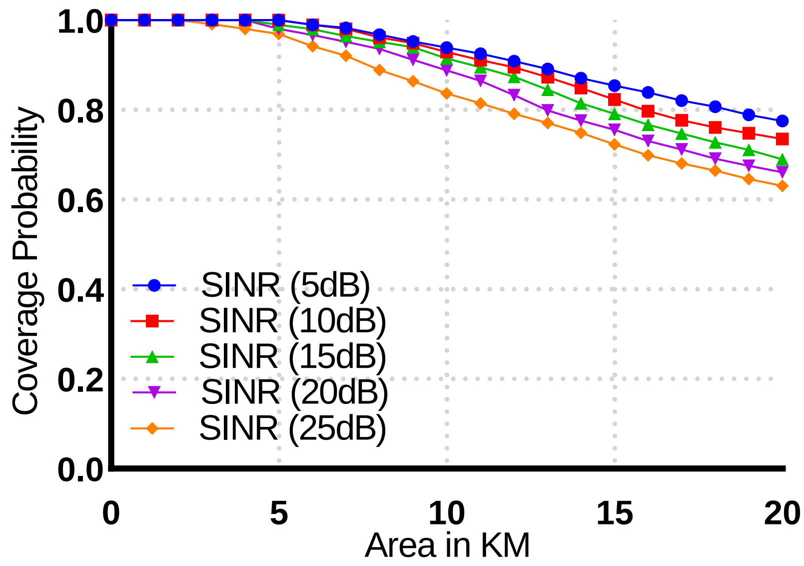


Figure 3.8: Measures different SINR value for the different length of area after 10% disaster.

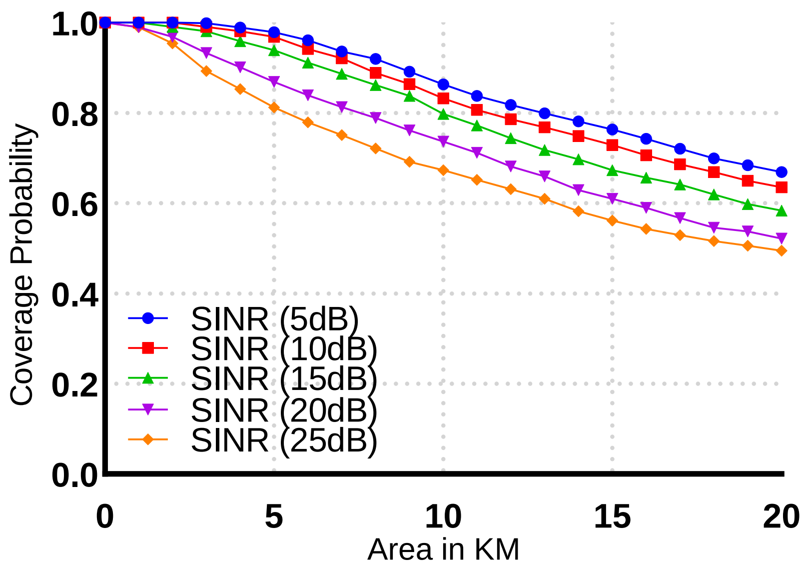


Figure 3.9: Measures different SINR value for the different length of area after 20% disaster.

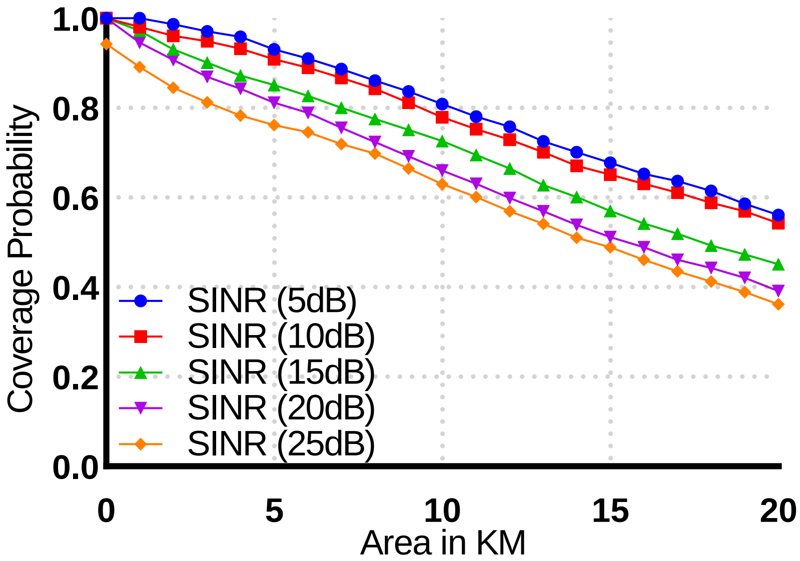


Figure 3.10: Measures different SINR value for the different length of area after 50% disaster.

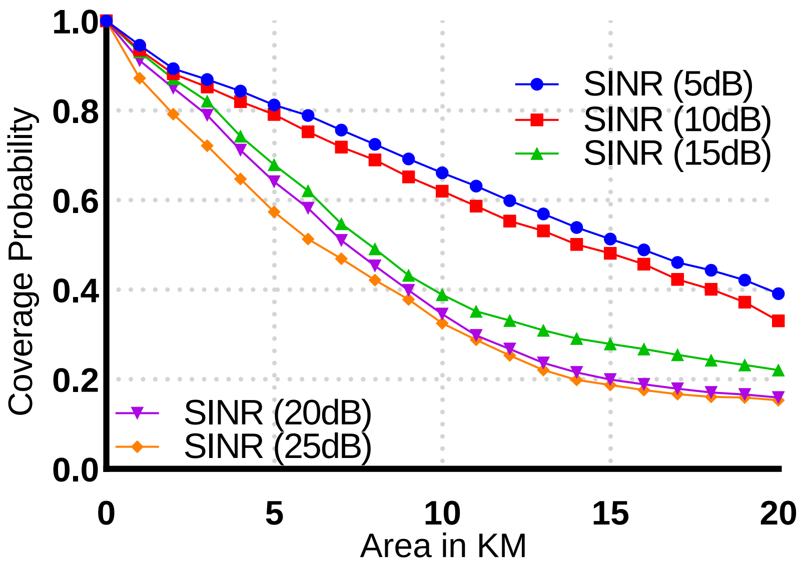


Figure 3.11: Measures different SINR value for the different length of area after 70% disaster.

The type of services the user will get for the different types of disaster effects is analysed. As it is higher, the value of SINR guarantees the Quality of Services (QoS) for the users. It also analysed the different SINR values for the different area size and determined how many users will able to get the QoS. Figures 3.8, 3.9, 3.10, 3.11 show the percentage of users who get different SINR value for the 10% -70% disaster impact. From Figure 3.8, around 70% of users will be able to use 25dB, which is a very good signal, and 80% user will able to get at least 5dB signal. On average 75% of people will be able to get 15dB signal in 20KM. However, if the effect of the disaster is high the outage probability will be high because of the distance and channel conditions. However when the disaster effect is 70%, QoS moves down. Only 20% of people get the QoS service in damage that is 25dB and 30% user will get 15dB. However, about 50% of users will get the service available for 5dB.

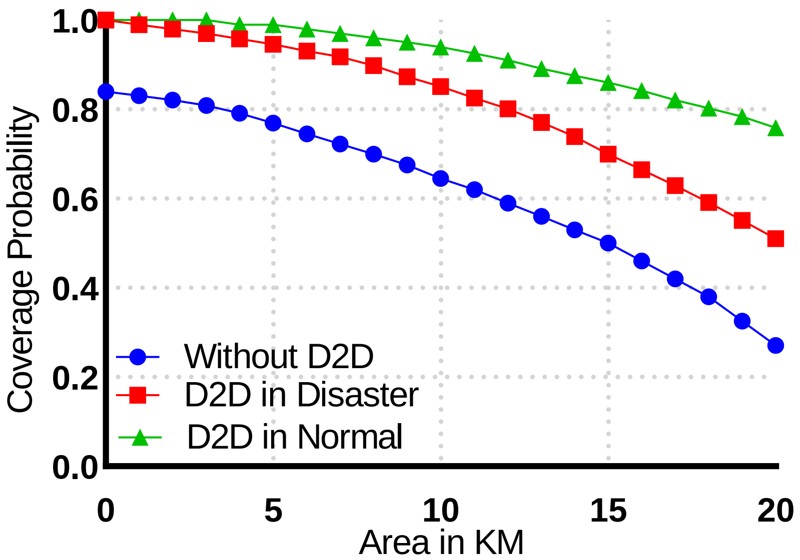


Figure 3.12: Network Coverage with D2D and without D2D.

The total outage probability is calculated with the three different hops, which are from the BS to UER, UER to CH and CH-to-CH (D2D) from the equation no 3.11, 3.13, 3.15, 3.17. The overall system outage probability increases as the node density increases, or when there is channel fading and interference increasing. It has also calculated the overall system coverage by using the cluster-based D2D communication in a normal scenario, and a disaster scenario, and when without cluster communication. Figure 3.12 shows that the overall network coverage probability with cluster and without cluster is significant difference. It has calculated for the 20% damage in 20KM with D2D and without D2D. The coverage percentage significantly increases with the increased size of area. With the cluster based D2D communication, overall network coverage is 20% more of any given km. In addition, in emergency communication network multi-hop communication extends the coverage. Moreover, CH to CH (D2D) communication reduces the consumption of energy and reduces the interference of entire nodes. The overall network coverage probability increases when using cluster-based communication. Figure 3.13 also shows the energy consumption for the coverage area. It clearly shows that using D2D communication is more energy efficient. In an emergency communication network, energy is one of the important factors. Using D2D communication is more energy efficient compared to non-D2D network communication.

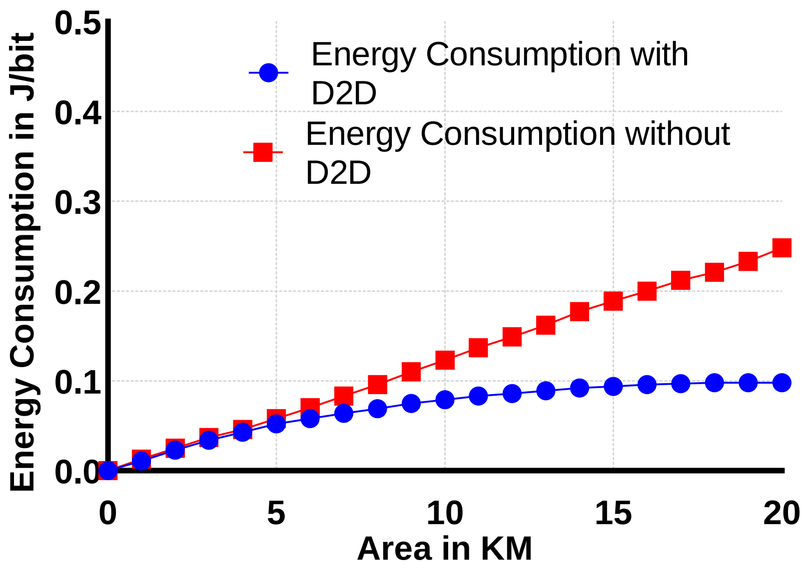


Figure 3.13: Energy consumption with respect to area.

The CH and multi-hop communication energy consumption is calculated, as energy plays an important role in the emergency communication network. The link between BS and the relay node is considered for the first hop communication. The energy consumption of this first hop communication is measured by the bit/Joule. Figure 3.14 shows the energy-efficient performance of the first hop communication. The result shows the different distances between the relay node and the BS. It also shows that energy efficiency decreases with the increase in the distance between the BS and the relay node. When the distance is 100 m between the BS and relay node, the energy efficiency is stable at .38 Mbit/J, because of the fixed bandwidth. However, when the distance increases between the BS and relay node, the path loss exponent will change, and energy efficiency will decrease.

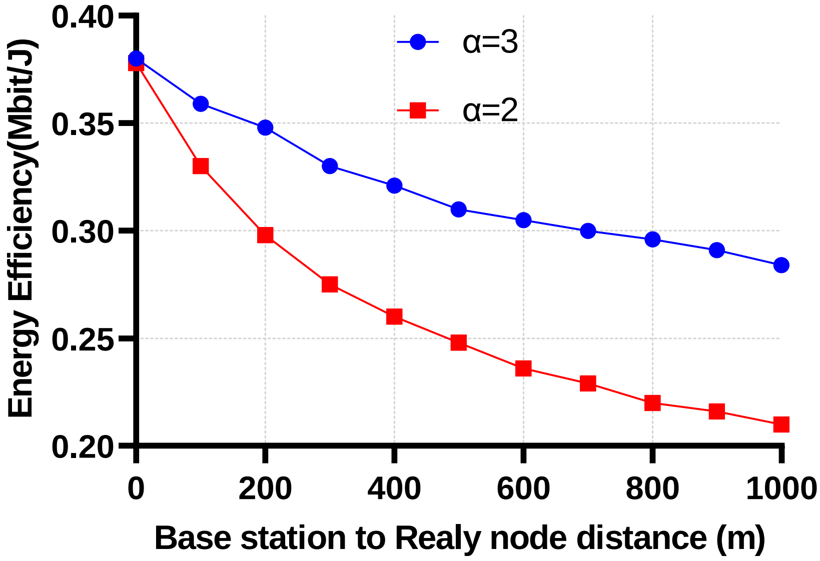


Figure 3.14: Energy efficiency vs the distance between BS to Relay Node.

Figure 3.15 shows the second hop energy efficiency with the different distances between the relay node and the CH. The distance between the relay node and the CH is considered to vary from 50 m to 250 m. The result shows that it required more energy than sending data from BS to the relay node. This shows a similar pattern of output when compared with the previous figure. However, the second hop required more energy as no fixed bandwidth exists.

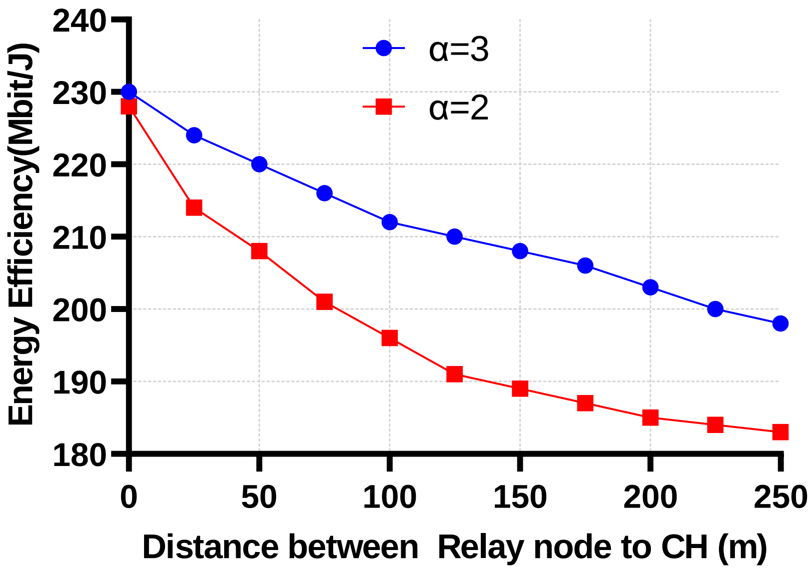


Figure 3.15: Energy efficiency vs the distance between Relay Node to CH.

Figure 3.16 shows the third hop energy efficiency with the varying distance from 0-50 m. A higher energy is required for the transmitted data as there is no fixed bandwidth. The path loss exponent value was also high, requiring higher transmission energy. For this, different path loss components do not greatly affect the data transmission.

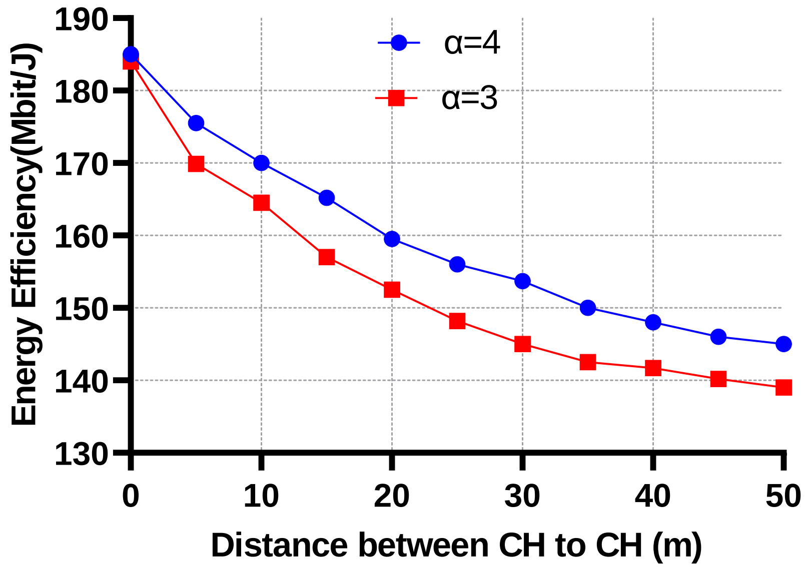


Figure 3.16: Energy efficiency vs the distance between CH to CH.

Figure 3.17 shows the cluster size vs the energy consumption of the CH. CH needs to be optimised to the maximum lifeline of the network. The result shows that a small size of the cluster is energy efficient, which results in the longest network lifetime and throughput. However, the energy consumption is increases with the increases size of the cluster. This is because, when the cluster size is big, all the nodes require higher energy to transmit the data to the CH, and even CH to CH also consume more energy to transmit CH to CH. However, without cluster formation energy consumption is more than communication via cluster.

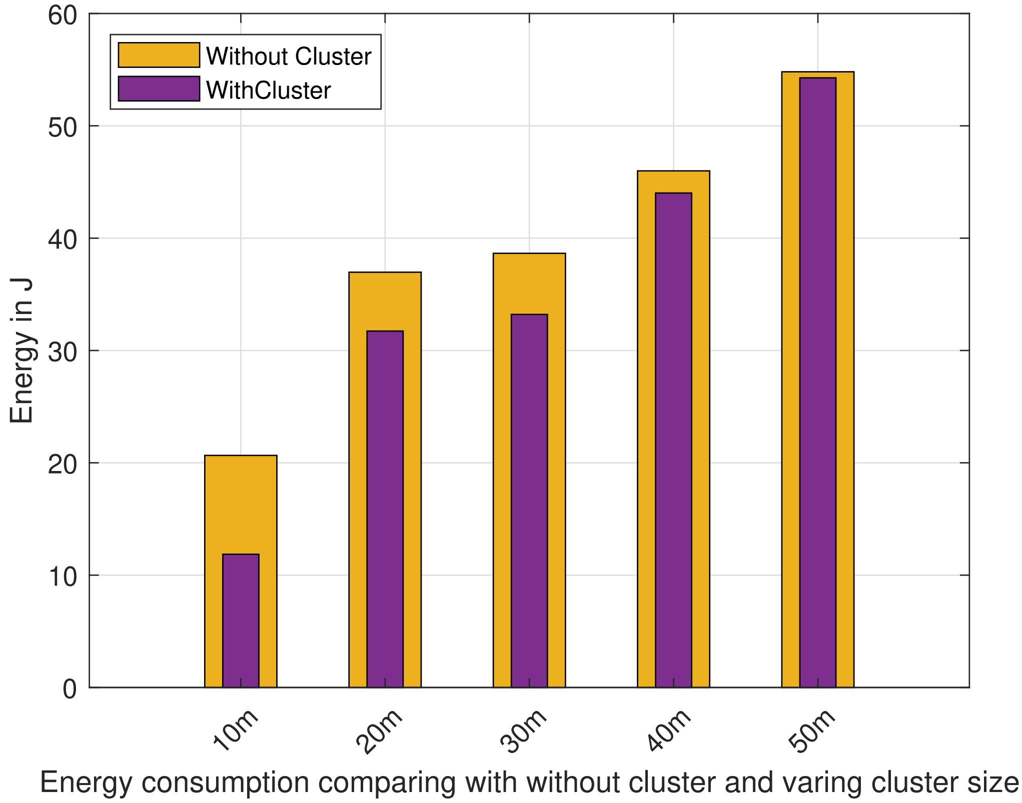


Figure 3.17: Engery consumption with respect to Cluster size.

From the above result, the significance of the D2D communication can be measured in the case of a disaster response system network. It also measured the percentage of users who can use the services after a disaster effect. This information can be used by the authorities for the prompt response system. SNIR value which is greater than 20 considered a good signal for communication services.

3.6 Summary

This chapter measured the performance of the clustering-based multi-hop D2D communication performance based on the outage probability and energy efficiency which are the important parameters for the emergency communication network. It shows the novel methodology by developing the mathematical model for the outage probability for both cellular and D2D users in multi-tier networks. The results show the outage probability for both cellular and D2D users for the different impacts of the disaster for the different SINRs. The results present the overall network coverage and network lifetime.

Chapter 4

Clustering and Routing Protocol

4.1 Introduction

Internet of Things (IoT) is a promising technology which can be used for the different applications used in disaster response system. The key element of the IoT infrastructure is a Wireless Sensor Network (WSN) which is used for sensing and monitoring the environment to reduce the effect of a disaster. For the WSN, energy is one of the major concerns, as sensors used in WSN are battery-operated devices. Thus, it is important to reduce energy consumption, especially during data transmission in disaster-adverse situations. Clustering-based communication helps reduce the nodes' energy decay during data transmission and enhances the network lifetime. Although there are many hybrid combination algorithms proposed for clustering and the routing protocol to reduce energy consumption, there is still a research gap in the combination of Particle Swarm Optimisation (PSO) and Butterfly optimisation algorithm (BOA) which are very popular optimisation algorithms. This chapter proposes a bio-inspired hybrid (BOA-PSO) algorithm where BOA is used for clustering and PSO is used for the routing protocol. The performance of the proposed algorithm is compared with the benchmark LEACH, DEEC, PSO, and PSO-GA. Residual energy, network throughput, and network lifetime are considered as performance matrices.

4.2 Background of The Chapter

The Internet of Things (IoT) focuses on an emerging paradigm to provide scalable solutions for a wide range of disaster problems. The objects (mobile phones, RFID tags, sensors, etc) in IoT networks have the ability to communicate with each other to perform a complex task by collecting data and processing it without human intervention. The Wireless Sensor Network (WSN) is the virtual layer of the IoT network[130]. WSN widely covers IoT applications, especially for environmental monitoring, and hazard detection. WSN-based IoT applications use several devices that are known as sensor nodes. These nodes are connected to the external network through a gateway, which is known as a sink or Base Station (BS). Sensor nodes collect the data from the environment and send it to the sink.

WSN is widely used in several applications for DRS including environment monitoring[131], disaster preparedness[132], Early Warning System (EWS)[133] and post-disaster response[134]. Figure 4.1 shows the application used in WSN for the disaster.

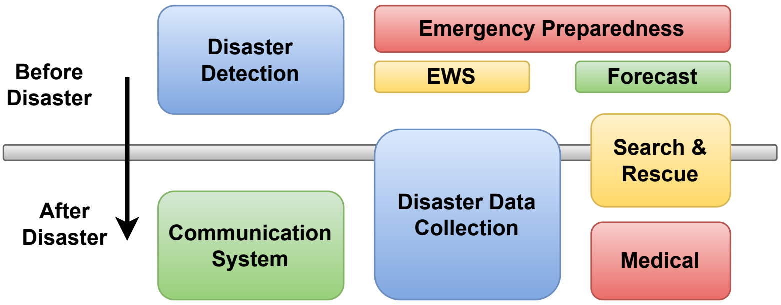


Figure 4.1: Different types of disaster applications for the pre and post-disaster.

However, there are limitations to using the WSN-based IoT network in disaster situations, which include limited battery life, power outage, limited memory, etc[135]. The fundamental paradigm of the network such as sensing the environment, data collection and transmission minimise the energy level of a node. The energy breakdown of the communication link between the nodes and the sink creates disruptions in the whole process. Under such a natural calamity, it is also not guaranteed that sensors or batteries will be replaced. The result is that the entire network fails and causes a delay in the response system. Hence, many researchers are working towards energy-efficient communication to increase the longevity of the network.

Clustering-based communication addresses these issues by providing energy efficient communication[136]. Clustering algorithm creates the group of the sensor nodes in a cluster. In every cluster, there is a Cluster Head (CH) which will be responsible for the data collection inside the cluster from nodes known as cluster members. CH also manage communication with the other CHs or the external gateway or directly with the sink. On the other hand, routing protocol also plays a significant part in reducing the energy consumption of the CH nodes. Transferring data to BS or other CH requires high energy. Therefore, an efficient routing protocol identifies the best route to transfer data between BS and the CH, which reduces the energy consumption to enhance the lifetime of the network[137]. Thus using an efficient algorithm to find the optimal CH and best routing protocol is essential for the WSN based IoT network in case of disaster response system network.

The main objective of this paper is to prolong the network lifetime by minimising the energy consumption of the node during communication between the node and the sink.

There are many researchers who have proposed and developed algorithms to enhance the performance of the WSN in terms of energy consumption, network coverage, network availability etc. As energy is one of the critical parts in measuring the WSN performance, extensive research has been conducted on clustering and routing algorithms. There are many researchers who have concentrated on swarm-based methods for the clustering and routing algorithm. Some of them used single metaheuristic algorithms for both clustering and routing algorithms, while others used a hybrid model. In this section, highlights some of the related previous research work.

To solve the problem, there are many algorithms that have been developed based on inspiration from nature on the different intelligent behaviours of birds, bees, fireflies, pigeons, and others. Some of the existing nature-inspired algorithms are Ant Colony Optimization (ACO)[138], Firefly Optimization Algorithm (FOA)[139], Artificial Bee Colony (ABC)[140], Roach Infestation Optimization (RIO)[141], Cuckoo Search Algorithm (CSA)[142], Honey Bee Mating Optimization (HBMO)[143], Particle Swarm optimization (PSO)[144], Pigeon-Inspired Optimization (PIO)[145], Bat Algorithm (BA)[146], Lion Pride Optimizer (LPO)[147], Butterfly Optimisation algorithm (BOA)[148], Lion Optimization Algorithm (LOA)[149], and many more. Out of them ACO and PSO have been extensively used by many researchers for clustering and routing algorithms.

The author [150] proposed ACO based clustering and routing algorithm for the IOT network. The author proposed routing algorithm using ACO for the different network. Mahalaxmi et al[151] develop a duel agent to optimise the performance of the different ACO algorithm.

Kaur et al[152] proposed an integrated PSO and ACO-based clustering method that enhances energy dissipation and data transmission rate. The author formulated the fitness function to use the parameter of residual energy and distance of the inter cluster to achieve data aggregation process. Lalwani et al[153] proposed a Harmony search algorithm (HSA) for the clustering and routing algorithm in WSN. The author used fitness function by considered the residual energy, distance between node to CH and CH-BS. The result showed that reduce of the energy consumption with the maximum distance between the node and sink. An integrated PSO and HSA-based algorithm was proposed by the author to achieve global search with rapid convergence rate. The result also showed that the consumption energy throughput increased instead of using the standalone algorithm PSO and HSA.

The author of [154] proposed a Genetic Algorithm (GA) for the cluster and routing algorithm for the WNS. The fitness function considered the residual energy, distance and routing phase. The result showed the sufficient improvement of the energy consumption and network lifetime.

Another bio-inspired energy efficient CH selection algorithm is proposed by an author using Artificial bee colony (ABC)[155]. The result showed the optimal number of clusters improved the network performance. There is a drawback in that the system was the CH using single hop to communicate with the sink.

This single hop problem was solved by the author using multi-hop communication between sink and CH and using the integrated ABC with the firefly algorithm. Lalwani et al[156] proposed a Biogeography-Based Optimization (BBO algorithm to be used for the CH selection. However, there is a limitation in the proposed algorithm's network lifetime as the traffic load is more in the CH and has a higher chance to die quickly. Integrated Cuckoo Search (CS) method is applied for the cluster and HSA being used for the routing is proposed by Gupta et al[157]. The main drawback of the proposed algorithm is the author proposed uniform distribution of the energy. The node near the sink consumed more energy due to the traffic loads.

Gao et al [158] proposed A PSO-based clustering and routing algorithm to optimise the energy consumption in WSN. The higher residual energy of a node considered as a CH candidate during the clustering process because the data aggregation between node to CH and CH to sink required more energy to the CH.

Morteza et al [159] proposed a novel fitness function using energy efficient, cluster closeness and using improved PSO-HSA.

From the above literature, it can summarised that the hybrid metaheuristic algorithm performs better than the single metaheuristic model for the clustering and routing algorithm in terms of energy efficiency. There has been no research conducted using a hybrid model BOA with the PSO for the clustering and routing algorithm. This study uses this hybrid model to measure the performance of the network.

In this chapter, a bio-inspired energy-efficient cluster and routing (BICR) algorithm is proposed for disaster response system network. The improved Butterfly Optimisation Algorithm (BOA) is used for the cluster formation, and, for the routing algorithm, Particle Swarm Optimisation (PSO) is used. BOA is a metaheuristic algorithm inspired by butterfly foraging and information exchange. Due to its enhanced performance, BOA is used in many applications in different domains. On the other hand, the PSO algorithm is dynamic, has prompt convergence and provides the highest throughput and reduces energy consumption compared to other heuristic and mathematic approaches.

4.3 Network Model

The network model used in this study is based on the assumptions mentioned below:

1. The network is considered a homogenous network. At the time of the IoT-based sensor deployment all, the nodes are isomorphic which means all the nodes have the same energy at the time of deployment.

2. The sensor node is operated by the battery and no energy harvesting method applied or not replenished is used.

3. The area covered by the IoT-based sensors are randomly distributed. The location of the sensors are fixed and each of the sensors nodes has a unique network identifier.

4. The entire sensor node perceives its own location. The distance between other nodes can be calculated using the Euclidean distance equation.

5. The base station has unlimited energy and computational power.

Figure 4.2 shows the network model considered in this study.

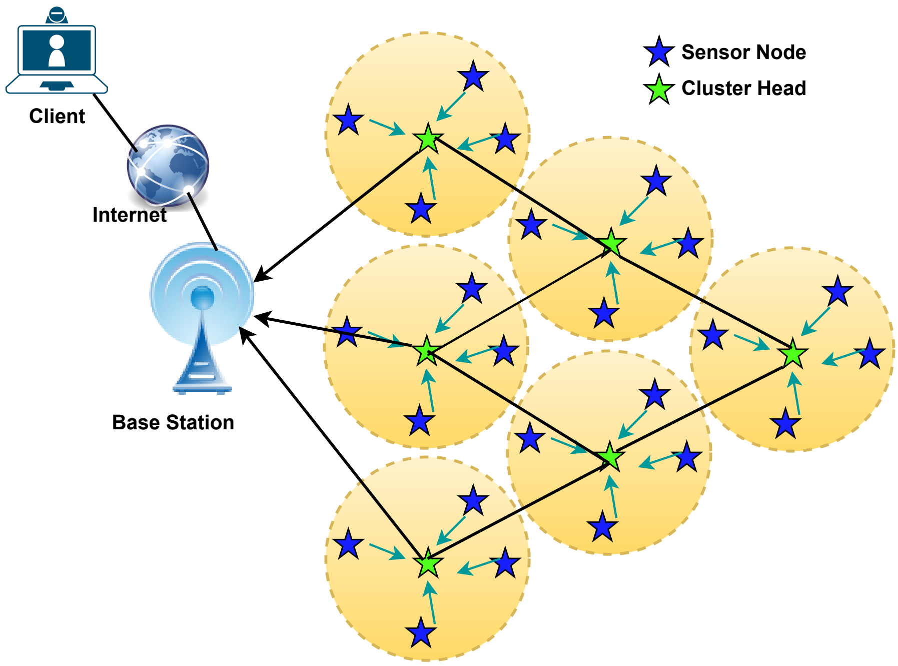


Figure 4.2: Cluster based sensors in WSN.

The first-order radio model which was presented by the author[160] is considered in this study. The ratio of the energy consumption model is based on the distance between the sender and receiver. Figure 4.3 shows the ratio of energy consumption mode where the energy consumption to send a message is calculated by the sender and receiver distance and the total length of the message.

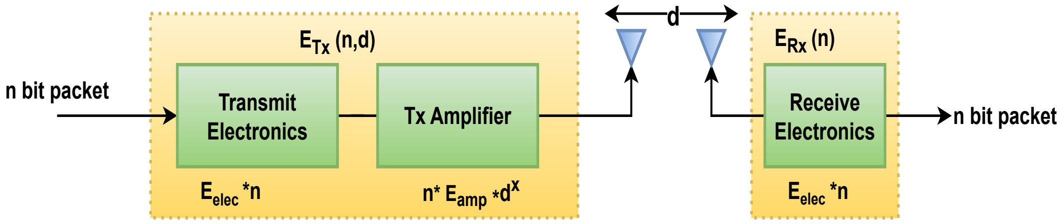


Figure 4.3: First order radio energy model.

$$E_{Tx}(n,d) = \begin{cases} n * E_{elec} + n * \varepsilon_{fs} * d^2, d \leq d_0 \\ n * E_{elec} + n * \varepsilon_{mpf} * d^4, d > d_0 \end{cases} \tag{4.1}$$

From equation 4.1, $E_{Tx}(n,d)$ is the required energy to transmit n bit over the distance d, E_{elc} is the energy required to transmit 1 bit.ε_{fs} is the amplification factor over free space model and $\varepsilon_{mpf}$is for the multipath fading model. d_0 is the distance threshold which is $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mpf}}}$. When the distance is less than the threshold consider free space model is considered and when the distance is greater than the threshold consider as a at multipath fading model. In addition, to receive n bit of data energy required $E_{RX} = E_{elec} * n$.

4.4 CH Formation

A butterfly uses chemoreceptors for sensing fragrance. As the butterfly moves to random places it spreads an intense label of fragrance. This fragrance helps to guide the butterfly agent to search for other butterflies. This also helps to find a mating partner. If any given butterfly fails to find a fragrance then it searches within the area in a random position, known as local exploitation. If the butterfly gets the intense fragrance then it move toward the butterfly, known as global exploration. The fragrance of a butterfly can be defined by the $f = CI^{\alpha}$. Where f is fragrance emitted by a butterfly, c is the sensory modality range [0,1] and I is the intensity of the fragrance and α is the power exponent. The equation 4.2 and 4.3 represent the local search and global serach [161]

$$x_i^{t+1} = x_i^t + (r^2 X x_j^t - x_k^t) X f_i \tag{4.2}$$

$$x_i^{t+1} = x_i^t + (r^2 X g^* - x_i^t) X f_i \tag{4.3}$$

where x_i^t is the solution vector for the i number of butterflies at t number iteration, r is random number [0,1], x_j^t and x_k^t are j butterfly and k bitterly, g* are the best solution is the current iteration. According to our network, each of the butterflies is initialised with an ID from 1 to N. N is the total number of sensors.

Every butterfly's position is denoted by the (Bi,p) that is belongs with (1≤p≤O) where O is the optimal number of CH. Assume that N is the total number of sensors in the A(axa) area. Considering free space energy consumption model, the energy consumption of a CH per round denoted as:

$$E_{CH} = n * E_{elec}(\frac{N}{O} - 1) + n * E_{DA} * N + n * E_{elec} + n * \varepsilon_{fs} * d_{bs}^2 \tag{4.4}$$

The energy consumption of a cluster member per round is denoted by:

$$E_m = n * E_{elec} + n * \varepsilon_{fs} * d_{CH}^2 \tag{4.5}$$

Energy consumption of the a cluster per round is denoted by:

$$E_{CPR} = E_{CH} + (\frac{N}{o} - 1) * E_M \tag{4.6}$$

Total energy consumption of the network for the O number of CH per round is denoted by:

$$E_{total} = E_{CPR} * O = n(2N * E_{elec} + N * E_{DA} + \varepsilon_{fs}(O_{BS}^2 + N * d_{CH}^2)) \tag{4.7}$$

The optimal number of CH can be found by the differentiating of O is denoted by:

$$O_{opt} = \sqrt{\frac{N * n}{2\pi d_{BS}^2}} \tag{4.8}$$

similarly, for multipath fading model, the optimum number of CH is denoted by:

$$O_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{fs} * n}{\varepsilon_{mp} * d_B S^4}} \tag{4.9}$$

4.4.1 Fitness Function

The cluster head (CH) selection will be based on the residual energy (R_S), node distanceN_D,and network coverage(N_C).

Residual energy: Residual energy is one of the vital factors in selecting CH as CH requires more energy to perform tasks. CH is responsible for receiving data from the node member and passing it to either another CH or to BS. Because of that, the node with higher residual energy has a high chance of becoming CH.

$$R_S = \sum_{i=1}^{O_{opt}} \frac{1}{E_{CH_i}} \tag{4.10}$$

From the equation, E_{CH_i} is the residual energy of the i^{th} cluster

Node Distance: This is also an essential factor for energy consumption. The less the distance node between the CH dissipation, the less energy there is for the transmission. The equation for the distance between the node and the CH is:

$$N_D = \sum_{j=1}^{O_{opt}} \left(\sum_{i=1}^{N_j} distance(CH_j, X_i)/I_j \right) \tag{4.11}$$

Network coverage: The higher network coverage was obtained by assigning the CH of the node. That node was not included with any other CH. This will provide higher scalability and increases the lifetime of the network. The network coverage is denoted as [162]:

$$N_C = \frac{(N * -D) - \sum_{D=1}^{D} C * M_D}{\sum_{D=1}^{D} C * M_D} \tag{4.12}$$

The fitness function use for the BOA algorithm for this study as below:

$$Fitness_{CH} = R_S * \beta 1 + N_D * \beta 2 + N_C \beta 3 \tag{4.13}$$

where$\sum_{i=1}^{3} 1, \beta_i \in (0, 1)$. For this study, it is assumed, $\beta 1$ is consider .50, $\beta 2$ is .30 and $\beta 3$ is consider .20.

The optimal CH selection process are given in algorithm-2.

Algorithm 2 CH selection algorithm process using BOA

```
Define the objective function from equation-4.13
Create a population of butterflies
Stimulus sensor modalityc, switch probability p and power exponent α.
while iteration ¡ maximum do
    for each butterfly in population: do
        calculate fragrance using
        update optimal butterfly population
    end for
    for each butterfly in population: do
        generate r (random number[0,1])
        if r¡p then
            move towards best butterfly using equation 4.3
        else
            moves randomly using equation 4.2
        end if
    end for
    update power exponent value α
end while
optimal solution for select the CH =0
```

4.5 Routing Protocol

Cluster Head (CH) collected data from the cluster member, and send it to the BS. It is assumed that CH maintains a list of the route of BS. The main objective of this routing algorithm is to minimise overall distance travel from source to destination as the distance is proportionally related to the energy decay and the network lifetime. The fitness function evaluates the quality of the routing protocol.

For this study, it has considered an improved PSO algorithm for the routing protocol. PSO algorithm [158] is a bio-inspired swarm of birds or fish moving in a multidimensional space in search of food. The CH node is considered as each of the particles and each of the CH was initialised of a random velocity and position.

let $P_i = P_{i,1}, P_{i,2}, P_{i,3}, ...P_{i,D}$ where D is equal to the optimal number of CH. Based on the intensity of movement and the deviation, the particles update the position. Particle's observer the (L_{best}) and (g_{best}) and then adjust the position and velocity as follows:

$$V_i^{t+1} = \omega * V_i^t + C1 * rand1 * (L_{best} - P_i^t) + C2 * rand2 * (g_{best} - P_i^t) \tag{4.14}$$

$$P_i^{t+1} = P_i^t + V^{t+1} \tag{4.15}$$

where, t is the current iteration, ω is the inertia weight ω^{max}=0.9 and ω_{min}=0.2. rand1 and rand2 are random numbers [0,1].

Each of the CH is assigned by a random number [0,1] from uniform random distribution. CH is connected with a random destination known as nearest relay node. It is assumed that, each of the CH is connected within the range of CH or the BS.The P_i, D is assign to the final destination node CH_D which is connected with the BS. Thus, the data sent from the source CH CH_S are sent to BS via CH_D.

The improved fitness function for the PSO algorithm are considered for the residual energy, distance between source and destination and the total number of relay nodes. The fitness functions are as follows:

$$Fitness_{PSO} = \beta 1 * \sum_{i=1}^{D} Distance(CH_S, CH_d) + \beta 2 * \frac{\sum_{i=1}^{D} E_r}{avgE} + \beta 3 * \sum_{i=1}^{D} relay(CH_S, Dest_d) \tag{4.16}$$

where, E_r is the residual energy, $AvgE$ is the average energy of all alive nodes and $Distance(CH_S, CH_d)$ is the distance between source and destination node.

Let us consider the network according to figure 4.4 where graph G(V, E) shows the vertex which is the CH acts as a gateway and E is the edge. Table 4.1 shows nodes within the range of a particular CH and the total number of the relay nodes. According to figure 4.4, there are 7 CHs (CH1, CH2, Ch3,. . . , CH7) connected with each other in the communication range. Every CH with a random number $P(i,d)\epsilon[0,1]$ is assigned which is mapped to a random relay node destination. Some of the CHs are connected to the BS. When the CH1 wants to send data to the BS, it can send through CH2, CH3, CH5 nodes.

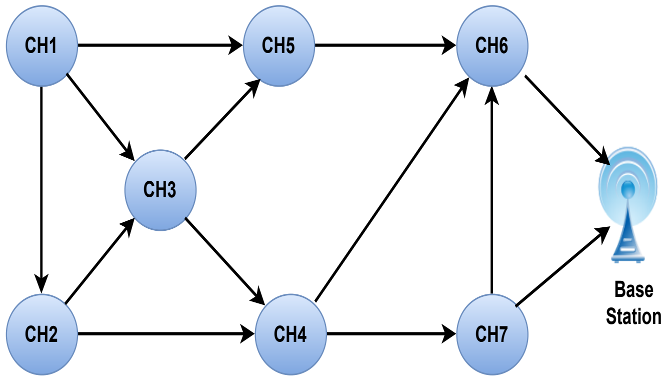


Figure 4.4: WSN topology for the 5 cluster head and one BS.

Table 4.1: Possible relay node of the CH.

Cluster Head	Relay Node	No of Relay Node
CH1	{ CH2,CH3,CH5 }	3
CH2	{CH3,CH4}	2
CH3	{CH4,CH5}	2
CH4	{CH6,CH7}	2
CH5	{CH6}	1
CH6	{BS}	1
CH7	{CH6,BS}	2

After the optimization process is completed with the fitness function, CHs have information about their members and the different routes to send to the other CH. To solve the issue of congestion and collisions, the TDMA scheduler is used. Each node has a dedicated slot to send data to the CH. The cluster member sends the data according to the specific time slot CH. The collected data is aggregated by the CH and sends it by the optimised route according to the proposed model to the BS.

After every iteration, according to equation 4.14 and equation 4.15, the particle position and velocity will update with respect to Pbset and Gbest. The updated new position value might get ≤ 0 or ≥ 1 because of algebraic addition and subtraction. To solve this issue, the regulated positions is used [163]:

$$P(i,d) = \begin{cases} 1 & \text{if } P(i,d) > 1 \\ min(\vec{r}) & \text{if } P(i,d) < 0 \end{cases} \tag{4.17}$$

$\vec{r}$ is a vector of random numbers [0,1].

Table 4.2 shows the optimization details route for the network. Figure 4.5 shows the optimization route for each of the CH to aggregate data and send it to the BS.

Table 4.2: Optimised relay path of the CH.

Cluster Head	Relay Node	No of Relay Node	$P(i,d)$	Relay Node
CH1	{ CH2,CH3,CH5}	3	.65	CH5
CH2	{CH3,CH4}	2	.73	C4
CH3	{CH4,CH5}	2	.96	C5
CH4	{CH6,CH7}	2	.52	CH6
CH5	{CH6}	1	.87	CH6
CH6	{BS}	1	.29	BS
CH7	{CH6,BS}	2	.18	BS

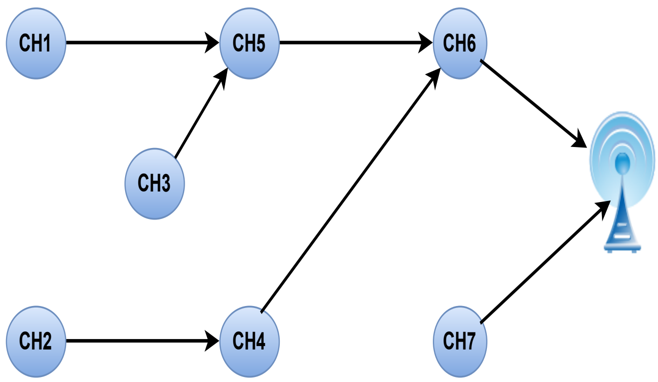


Figure 4.5: Optimisation path for the IoT network.

The algorithm-3 shows the method to select the optimal routing path.

4.6 Simulation Results

The simulation was conducted to validate the proposed model. Matlab 2019b is used to perform the simulation. The properties of the Matlab installation environment are as follows: Windows 10 64-bit operating system, Intel(R) Core(TM) i7-6700 CPU @ 3.40GHz, 16GB RAM. To validate the model, our proposed model's simulation result is compared with the traditional model LEACH [160],DEEC [164] and state-of-the-art meta-heuristic algorithm based on PSO[165] and hybrid models PSO-GA[166]. The parameters used for this simulation are given in Table 4.3.

Algorithm 3 Optimal routing path selection algorithm for the PSO

Define the objective function from equation-4.16
Input: Optimal number of CH $(CH_1, CH_2, CH_3, ..., CH_N)$
Initialise of particles (P_i)
Initialise swarm S_n
for $i = 1$ to S_n **do**
  compute fitness value using equation-4.16
  L_{best}←P$_i$
end for
while $iteration > Maximum$ **do**
  for $i = 1$ to S_n **do**
    update the velocity and position of each particle
    Evaluate the value of P_i using equation-4.16
    if $L_{best} > currentvalue$ **then**
      $L_{best} \leftarrow P_i$
    else$G_{best} \leftarrow L_{best}$
      select the best fitness value
    end if
  end for
end while
Optimal routing path by finding optimal relay node

The simulation is considered two scenarios for the 200X 200 m area.

Scenario-1: This scenario is considered as a normal situation where BS/Sink is located in (100,100) locations. All the sensors are around the BS for short-length communication.

Scenario-2: This scenario is considered a disaster situation where BS/sink is located in a (0,0) location. All the sensors are far from the BS for long-range communication.

This simulation will help to understand and compare the proposed model stability in different situations with different models.

Table 4.3: Simulation parameters.

Parameters	**Value**
Initial Energy E_o	0.5j
Transmission and Receive Energy (E_{elec})	50(nj/bit)
Multipath Fading (E_{amp})	0.0013pj/bit/m^4
Free space transmitter amplifier energy (E_{fs})	10 pj/bit/m^2
Power exponent	0.1
Sensory modality	0.01
Particle Position (X_{min}, X_{max})	$0, 200$
particle Velocity(V_{min}, V_{max})m/s	$0, 200$
No of Round	2000
No of Iteration	5
Swarm Size	15
Acceleration Constant	2

The following performance matrices are considered for the validation of the proposed model:

- **Residual Energy**: The sum of all the alive sensors' node remaining energy is considered as a performance matrix to evaluate the model. The residual energy is directly related to the energy usage within the network and influences the network lifetime.

- **Throughput**: This is another important performance factor to evaluate the protocol. Throughput defines how much information the client gets from a monitoring area that the sensors collect and send. It measures how many packets the BS receives from the sensor node.

- **Network lifetime**: The main objective of this proposed model is to maximise the network lifetime. This is to measure how much node is alive and able to send information to the sink. As mentioned above this matrix is directly related to the residual energy of a node.

Figure 4.6 and 4.7 presented the average residual energy of all the nodes for the scenario-1 and scenario-2 respectively. The residual energy of the proposed model is compared to the LEACH, DEEC and PSO models. For the calculation of the residual energy, 200 nodes are considered for both scenarios. According to the figures, the proposed model achieved the higher residual energy for all the nodes with the different numbers of round.

For the scenario-1 (figure 4.6) For the LEACH and DEEC model all nodes residual energy empty after 1200 round. PSO performs better than the LEACH and DEEC. The residual energy became low around 1450 round. However, proposed model perform much better than LEACH and DEEC, the residual energy finishes after 1957 rounds.

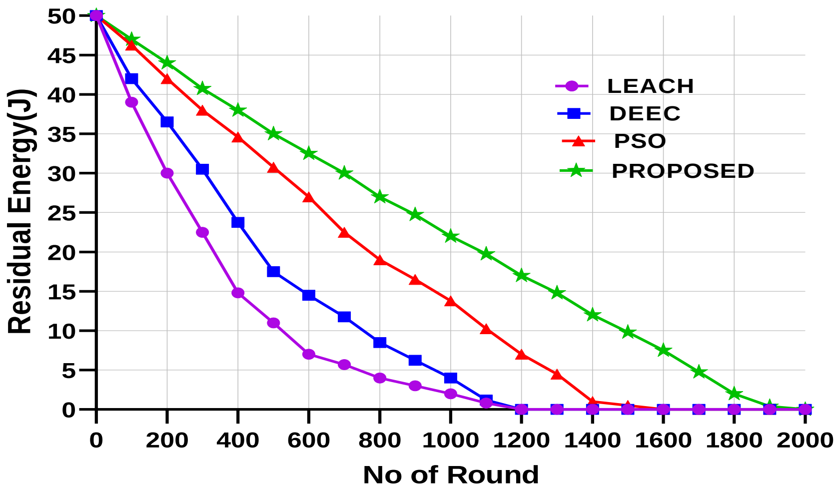


Figure 4.6: Residual Energy for the scenario-1.

On the other hand, for the scenario-2 LEACH, DEEC and PSO's residual energy died at 967, 1187 and 1325 rounds respectively. However, the proposed model finished after 1600 rounds. The reason for the finished residual energy for the LEACH was higher energy consumption for the selection of random CH and single hop data transmission. For the DEEC algorithm optimal distance was not considered when selecting the CH. The PSO considered the residual and distance of BS, but did not consider the distance between two CH and the orphan node. The proposed model performed better as it is considered for higher residual energy, distance as well as orphan node for the extent of the network lifetime.

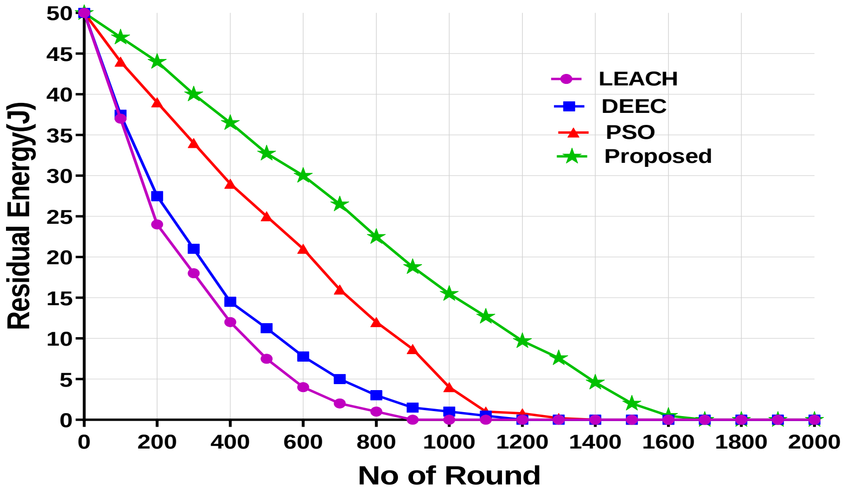


Figure 4.7: Residual Energy for the scenario-2.

Figures 4.8 and 4.9 show the network performance throughput for the proposed model and compares it with the LEACH, DEEC and PSO for scenario-1 and scenario-2 respectively. The throughput was also measured by changing the different nodes. For both scenarios, the network throughput for the proposed model was significantly higher compared with the other protocols. The proposed model has higher throughput from 10%-20% than the other models. The reason is that the proposed model fitness function was considered to use less energy consumption during data transmission to achieve a higher network throughput.

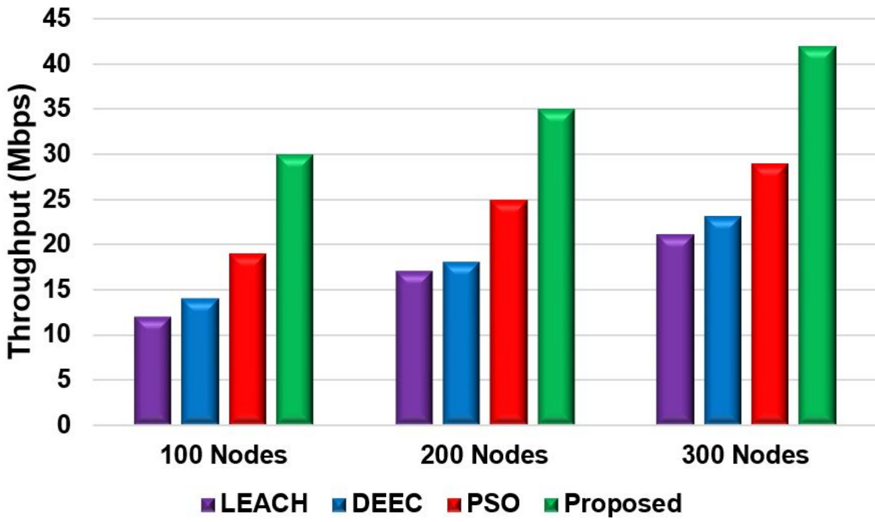


Figure 4.8: Throughput comparison of different nodes for the scenario-1.

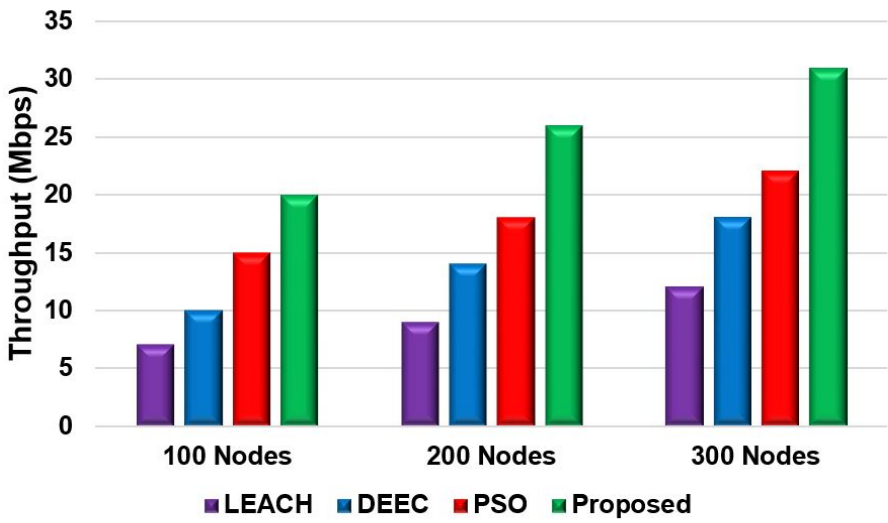


Figure 4.9: Throughput comparison of different nodes for scenario-2.

Figure 4.10 shows the total packet received by the BS. The scenario-2 was considered with 200 nodes for this evaluation. More than 18000 packets were received by the BS for the proposed model. However, LEACH and DEEC could not send enough packets, compared to the PSO. The proposed model sends more than 12000 packets compared to the LEACH and DEEC and 4000 packets higher than PSO. The reason for that is the proposed model fitness function preserves the residual energy for the nodes which increases the nodes' lifetime. This will help to enhance the network lifetime and also increase the number of packets that transmit to the BS.

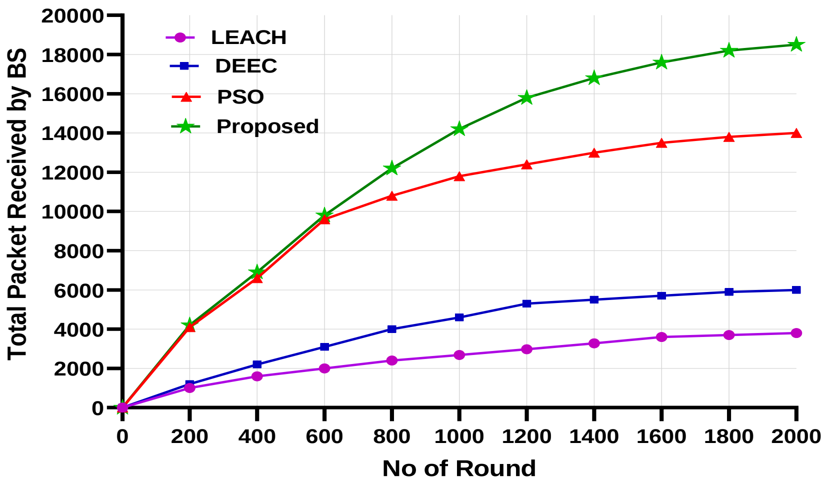


Figure 4.10: Number of packet received by the BS.

Figure 4.11 shows the packet drop ratio for scenario 2 with the different nodes. The proposed model achieved a lesser packet drop ratio, compared to the other models. LEACH and DEEC have significantly higher packet drop ratios for the different numbers of nodes compared with the proposed model. The packet drop ratio in the proposed model increased by approximately 5% with the increase of 100 nodes. The proposed fitness function helps to minimise the drop of the data transfer as the model selects the energy-efficient shortage path to send the data. However, the PSO model achieves a lower percentage of drop ratio because of the routing efficiency. Nevertheless, due to the inefficient selection of CH and routing path, LEACH and DEEC have higher packet drop ratios.

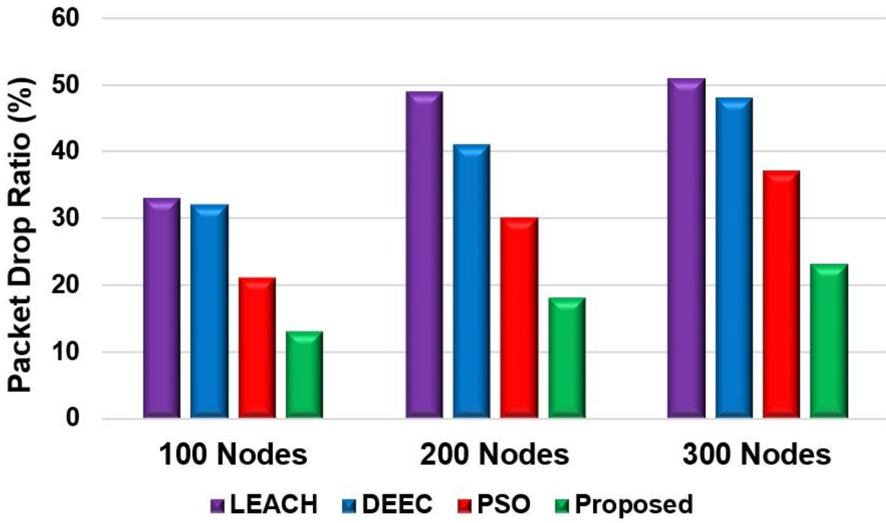


Figure 4.11: Packet drop ratio for the different nodes in WSN.

Figure 4.12 and 4.13 shows the percentage of improvement of the network lifetime of the proposed model for scenario-1 and scenario-2 respectively. The proposed model also compares the state of art PSO and Hybrid models. The proposed model has achieved significant improvement in the network lifetime and increases from 27%,24% and 21% for scenario-1 for the 100 nodes, 200 nodes and 300 nodes respectively. For scenario-2 (Figure-4.13), shows the proposed model increased of 23%, 21% and 17% for the 100,200 and 300 nodes. The proposed model achieved a higher network lifetime compared with the other state of art models, the network lifetime increasing by approximately 10%. The reason is the significant CH selection process, preventing energy consumption of the node during packet transmission, and finding the optimised route for the packet delivery.

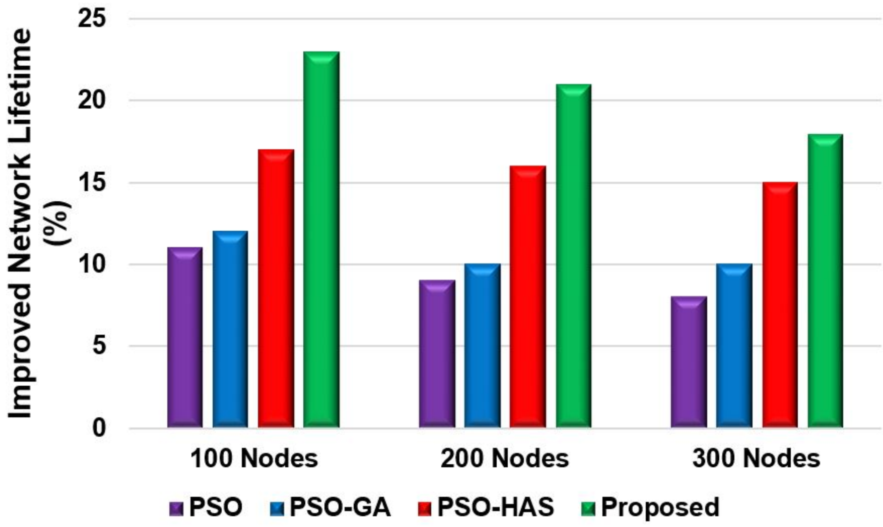


Figure 4.12: Percentange of improved network lifetime for the scenario-1.

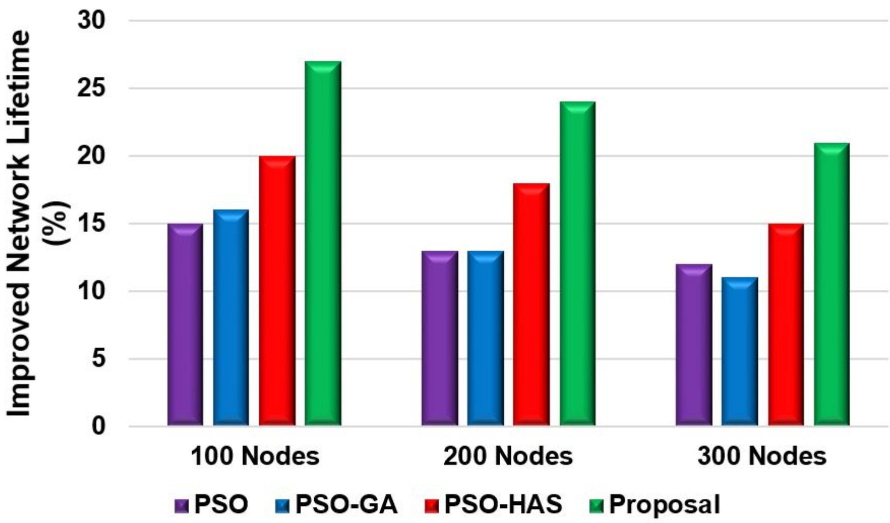


Figure 4.13: Percentange of improved network lifetime for the scenario-2.

4.7 Summary

In this chapter, a bio-inspired optimisation algorithm model is proposed for selecting the energy-efficient cluster head and optimal routing protocol. The proposed model aims to increase the network lifetime, and reduce energy consumption, which are vital parameters for the IoT network in a disaster. For selection, the CH and routing algorithm's effective fitness functions are used, which ensure the enhancement of the performance of the model. The analysis assumes a different situation by placing the BS in different location. The proposed model is compared and evaluated with the benchmark models that are used in CH based routing protocol for the IoT network. To evaluate the proposed model residual energy, network throughput, packet delivery and network lifetime are considered as the performance matrix. The experimental results show that the proposed model significantly enhanced the residual energy, network throughput and increased network lifetime by 10%-20% compared with the LEACH, DEEC, PSO and hybrid PSO.

Chapter 5

Data Security Model for D2D Communication

5.1 Introduction

Integration of the emerging technologies like Device to Device (D2D) communication and the Internet of Things (IoT) plays a significant role in the current disaster response system. However, several critical security issues exist, which have attracted researchers' attention, especially Blockchain (BC), which is a robust technology that could solve D2D and IoT devices' security issues. This section analyses and discusses the security issues for early and post-disaster communication systems. It proposes a Hyper ledger Fabric (HLF) Blockchain-based communication model for the disaster communication system that will overcome security threats and enhance the response system by providing an authenticated and authorised participant node. This chapter implements the HLF Blockchain framework to validate the proposed model and measure the system performance matrices.

5.2 Background of The Chapter

A secure framework is mandatory to interact with the infrastructure and produce reliable and valuable data from external sources. That data then must be analysed to provide information so that the first responder has more accurate and precise information to accomplish the complex task. Device-to-Device (D2D) and the Internet of Things (IoT) under 5G systems are emerging technologies that can play a significant role in enhancing the performance of the response system. They do this by providing delay tolerance early warning and post-disaster communication to affected people. Adopting these emerging technologies can fulfil the emergency response system's requirement due to low latency, low energy-based communication, scalability, reuse of the frequency spectrum, and the high volume of data. In contrast, security, privacy, and trust are the primary challenges of 5G-enabled IoT networks due to the heterogeneous devices. These devices are from different vendors using various technology protocols and prototypes, creating a significant security concern regarding the integrity of data generated from the devices. These devices can also generate massive amounts of data collection and transfer via the wireless network, which causes network traffic congestion, and delays tolerance communication. D2D communication can manage this network traffic congestion. However, Data security in D2D communication is one of the major concerns. Thus, a decentralized Blockchain-based security framework must integrate with the existing infrastructure to maximize the benefit of 5G-enabled IoT and D2D communication in case of an emergency network. Blockchain is a peer-to-peer technology that records information in an immutable and secure ledger. The risk of altering and changing the stored data within the Blockchain ledger is low. It consists of a digital ledger of the transactions stored in the distributed network of the computer systems on the Blockchain system.

5.3 Disaster Network Security Threat

An effective disaster response system could save many lives, property, and wealth. Figure 5.1 shows the model used for data gathering and the process of DRS framework.

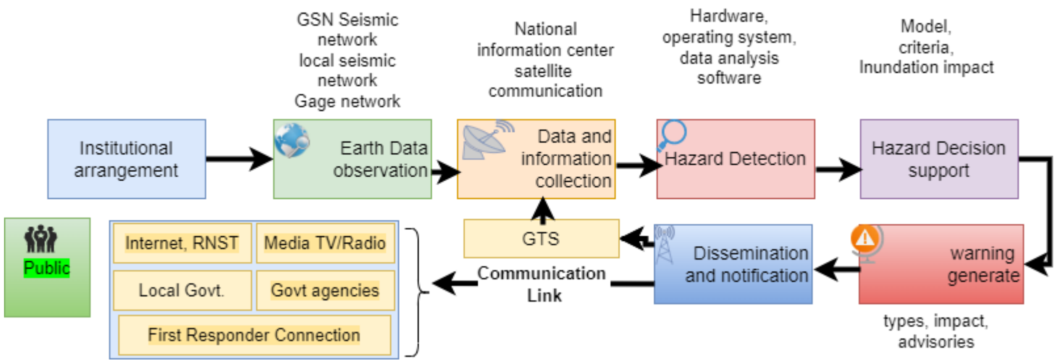


Figure 5.1: Architectural model for the disaster response system/communication system.

This model is divided into two main parts: An early warning system and the post-disaster communication system. In both cases, a secure, valid, and trustable data source can enhance the response system's performance in the disaster response system.

In the case of the pre-disaster early warning system from Figure 5.1, data were collected from various sources, sensors or IoT devices and passed to the National information centre, where information was processed to decide about the adverse situations. If any adverse situation arises, the information is sent to the public. However, if the data sent to the national information centre is not accurate or valid, the analysis will not generate accurate information about the disaster. On the other hand, after the disaster has struck, there is a high chance of BS damage. No active BS means communication links are broken between the national emergency authority and the people, causing outage problems. In this situation, cluster-based D2D communication can overcome the outage problem. Without the BS, the communication link can be established using D2D communication from the damaged area to the healthy network coverage area. As D2D is used to direct communication between the device and to devices, the user identity process (Authentication, Authorisation) processes are more complex and vulnerable, which causes the impersonation attack in the system [167].

In traditional LTE mobile communication, the core network uses EPS Authentication and key agreement to identify and tackle malicious users. They are impersonating other identities to access communication services. The traditional authorisation algorithm cannot handle the authentication process among the devices in D2D communication outside of the coverage area[168]. As a result, malicious users can manipulate the user data, eavesdropping on the transmission signal and channel, which are very high risks of security threats. Thus, D2D communication lacks security to provide data confidentiality and integrity during transmission, especially when users have mobility.

There is another D2D communication threat that occurs due to the interferences of the devices in the network: Interference between UEs creates frequency, and the interference integrates extra messages. This interference generates a higher volume of messages received by malicious users than by authenticated users. This threat is known as wiretapping [169]. In cluster-based communication, nodes inside the cluster transmit data to the Cluster Head (CH), and then CH transmits to the other CHs. There may be some malicious nodes/users participating in a cluster. However, it does not transfer any data to the other node, which creates congestion of the channel and consumes energy. This threat, known as a free-riding attack [170], is a security threat where the network must send and receive a high volume of data, causing unnecessary traffic. In both pre- and post-disaster communication, the network must handle a high volume of data to transmit and receive over the network so that these data can be analysed and precise information can be obtained. Nevertheless, due to the security threat, there is a big question about the data validity and trust in the case of the disaster response system network.

Although there are many researchers who have proposed different solutions to the concerns about D2D security [171–176].

To accomplish data security in D2D communication, Zhang et al [173] developed a technique that combines public-key cryptography and symmetric encryption. Combination of a public key-based digital signature with a cellular network's mutual authentication mechanism to ensure entity authentication, data authority, integrity and transmission non-repudiation. Furthermore, symmetric encryption ensures data confidentiality. The scheme's primary benefit is that it can recognize free-riding attacks by keeping track of the present status of the UEs. The drawback of the system is the communication between the eNB and the GateWay (GW) is considered to be safe, whereas, in an adverse circumstance, the channel may be compromised.

The authors of [174] proposed end-to-end secure key exchange techniques for communication. During communication, D2D users can conceal their identify and group details. Based on digital signatures and mutual authentication, Public Key Cryptography (PKC) provides user authentication and integrity. Data privacy is further enhanced by symmetric encryption.

Mohseni et al [177] proposed Evolved Packet System-Based Authentication and Key Agreement (EPS-AKA) as a protocol for enabling secure authentication to all network devices. This protocol is extensively used to authenticate both the User Equipment (UE) and the network in LTE-based networks. Goratti et al [178] suggested a Secure Data Exchange Approach for LTE-Advanced Networks of the D2D Communication. The suggested method is based on a Fourth-Generation (4G) network.

To build direct links between D2D devices, Goratti et al [175] proposed a security communication protocol. To establish D2D communication, the protocol transmits a beacon to adjacent devices and then utilizes an unidentified pre-distribution encryption key for authentication.

The suggestion made by the Gaba et al [176] end-to-end verification, and this has been carried out via Identity-based Cryptography (IBC) based on ECC. This simplifies setting up the system on confined IoT devices.

Thai et al[179] outlined a scheme for generating secret keys using multiple untrustworthy relays. For untrustworthy relays, the key generation system employs zero forcing and a channel appraiser with a minimum mean square error (MMSE).

In addition, the authors [180] applied the Secure Message Delivery (SMD) protocol to send data from source to destination in an encrypted way. Their strategy resolves the problem of secure message delivery. Defenders are D2D users who recognize all trustworthy network devices. The intruders transmit various malicious messages into the D2D network.

Though, there are a number of solutions designed for data security of D2D communication in a disaster response system. However, the proposed solutions are unsuitable for 5G network-based D2D communication and fail to meet critical security criteria due to the distributed nature of the communication. To overcome the security issues in D2D communication, there are many researchers suggested to use of Blockchain technology. The authors[181] focused on different problems for the Emergency Management services and provided a solution using Blockchain technology. The authors also discussed the enhanced performance for data sharing, security, privacy and minimising the administrative workload.

Data security can have negative effects on disaster management communication. McIsaac et al [182] suggested Blockchain technology to minimise the impact of security. Blockchain technology and cryptography to protect the identifity theft during the natural disaster response system.

Samir et al[183] suggested a distributed blockchain-based trust management framework for enabling cooperative unidentified assistance to be established during disasters while taking infrastructure into account. Nawari and Ravindran [184] investigated the prospective use of blockchain in post-disaster recovery and reconstruction. The author suggested a novel integrated framework that incorporates blockchain into the building data modelling workflow, potentially simplifying the post-disaster reconstruction process.

5.4 Proposed Model

This paper has proposed both the pre-disaster and post-disaster security models in emergency communication for a prompt response. Figure 5.2 shows the security model for pre-disaster, and figure 5.3 shows the security model for post-disaster D2D-based communication. In both models, HLF Blockchain technology has been integrated, which executes the smart contract and configures the consensus and member verification servers that enhance the security system and data integrity.

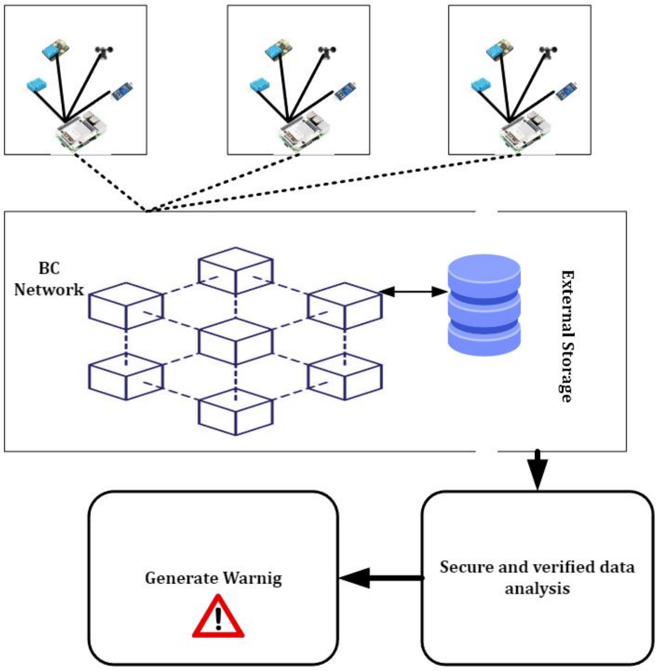


Figure 5.2: Blockchain-based early warning system model.

From Figure 5.1, the disaster management model consists of numerous vendor devices with different processing capabilities, data transmission, and security protocols. Thus, a generic security platform is required to provide the security of each device and each layer. This chapter proposes that each of the collectable IoT devices is connected with the Edge devices in a geographical area, known as a cluster. Every collectable IoT device is known as a node, and the edge device is called CH. The node devices will collect the sensing data and send it to the edge device (CH). The edge device maintains the identity of each node connected with the CH by using the smart contract. The edge device is also responsible for data collection, route selections for data transmission, local authentication and authorisation, and overall network management. The collected data must send in into a distributed network where the Hyperledger Blockchain service runs to get the Blockchain services. The Blockchain maintains the distributed ledger of the entire network edge devices. Consensus algorithm and smart contract services are also maintained by the Blockchain service to provide data consistency, scalability, and traceability of the data sent by the node devices. Entire edge devices connected run local authentication processes to verify the nodes associated with the devices. Chain code is used for the deployment and request services.

IoT device registration and authentication services are retrieved through the API server. These provide several services for disaster-related applications. The local authentication and authorisation process must be completed before transaction submission. The registered IoT devices sign a transaction using the private key, and chain code is used for the appending data and stored in the ledger. This code maintains an executable logic hosted in the node devices. Parallel execution needs to be implemented for the data processing to increase the overall system performance. The node devices' data is now processed by the chain code using parallel processing to analyse the data checksum, validation, and ownership of the data in the Blockchain. The cloud server or the distributed BS network manages, processes, and transmits the node devices' data. This verified data is now stored in the Hadoop system's external storage to analyse, using the Big Data technology for further analysis to predict the disaster or warning. The stored data must be verified using the file ID in the blockchain and compared with the original data with stored data before analysing. This data ensures further accurate information about the disaster.

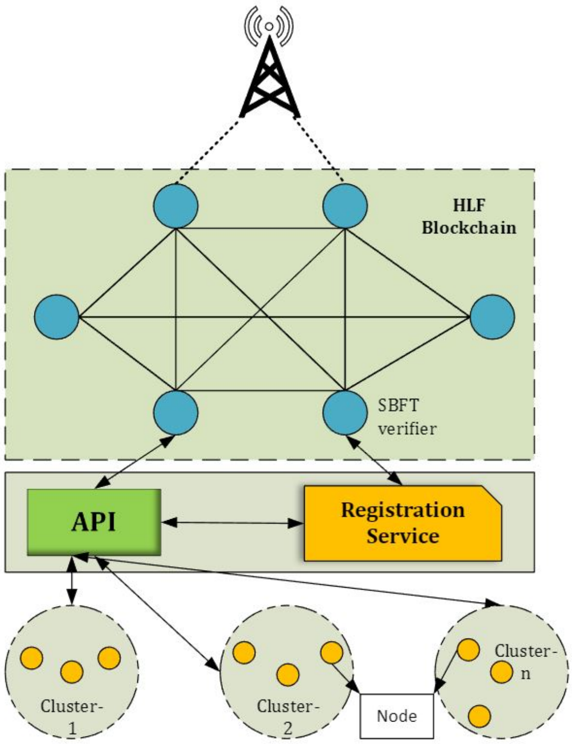


Figure 5.3: Blockchain-based post-disaster communication model.

In the case of a post-disaster network, the communication is done through CH to CH using D2D communication. For this communication, CH provided intra-cluster privacy and security. CH processed the request coming from the node devices and verified it. A lightweight session key is integrated with the device when the devices want to send data to the CH. This session key authorises the node to validate the data and establish communication, and then the CH validates the session key to provide local authentication and authorisation. This process enhances the scalability of the heterogeneous device network, especially for the 5G network. CH is also responsible for maintaining the local ledger for registering the new device that wants to connect with the cluster. This process helps to solve the mobility problem discussed above. In summary, CH is responsible for four things:

1. A new node registration in the cluster and maintaining a local ledger.

2. Crypto-graphical key distribution and implementation.

3. Initialisation of the secure communication establishment.

4. Secure communication management.

The model proposes a symmetric key and lightweight cryptography to maintain a ledger for the local registration used for authentication and authorisation. This system also solves the scalability and identification problem in the D2Dnetwork. The symmetric key is encrypted by the lightweight session key, also known as the distribution key. When communication occurs within the D2D network, that session key protects that communication. The session key has a unique identifier and a validity period. The lightweight cryptography key is used for message encryption, validation, authentication, and decryption for secure communication in the D2D network [40]. Thus, a distributed blockchain model can overcome security limitations in the D2D network in case of disaster communication. The proposed model is based on the Kafka distributed consensus algorithm, which provides the decentralised Blockchain method for secure data communication. Kafka consensus algorithm defines and manages the security of all the nodes participating in the communication. In the blockchain network, each node must finalise the configuration with the Hyperledger, NodeJS, to create the blockchain pool. After verification, the authentic nodes can participate within the cluster. When a new node comes into the block, the verifier broadcasts the node's information to the other nodes to update it. To do the broadcast, the verifier first searches the previous node information; if the previous node is registered, then the broadcast steps skip to reduce the broadcast time. The authenticated node can participate in the consensus process. When any nodes request the block, the SFBT calculates each node's Resource Uses (RU) and other communication parameters for the entire network to validate the contract. This is how the system verified the free-riding node. The interaction between the CH and other network elements have been done through the HLF blockchain.

The HLF blockchain is used for numerous transactions for data collection, process, and distribution. Smart contracts can describe the transaction. BS is connected with the CH, and this is separated from the Blockchain network. The transaction is handled by the CH and provides a shared channel for the different peer-to-peer network communication. This transaction also handles the ordering services, including the verified message broadcast.

5.5 Results and Discussion

Blockchain simulation environment is implemented to analyse the performance of the proposed system. Blockchain applications were used to verify the participant in the network, to verify the participant's transactions, order process, create a block, store the transaction in the network, and maintain the transaction in a ledger. Figure 5.4 shows the high-level architectural view of the development environment. The below metrics are considered for analysis to evaluate the system performance:

1. **Memory utilisation:** Memory uses the total memory occupied to process and store the transaction.

2. **Latency:** the total time required to create one transaction and store the transaction in the distributed ledger.

3. **Throughput:** the highest number of transactions that the system can handle and store the transaction in the distributed ledger in each timeframe. The matrices are chosen considering the disaster data communication as it is required to process data faster despite the security.

Fifty (50) logical nodes have executed the request used in the experiment. All the nodes send the transaction request to process the order with the different transaction sizes.

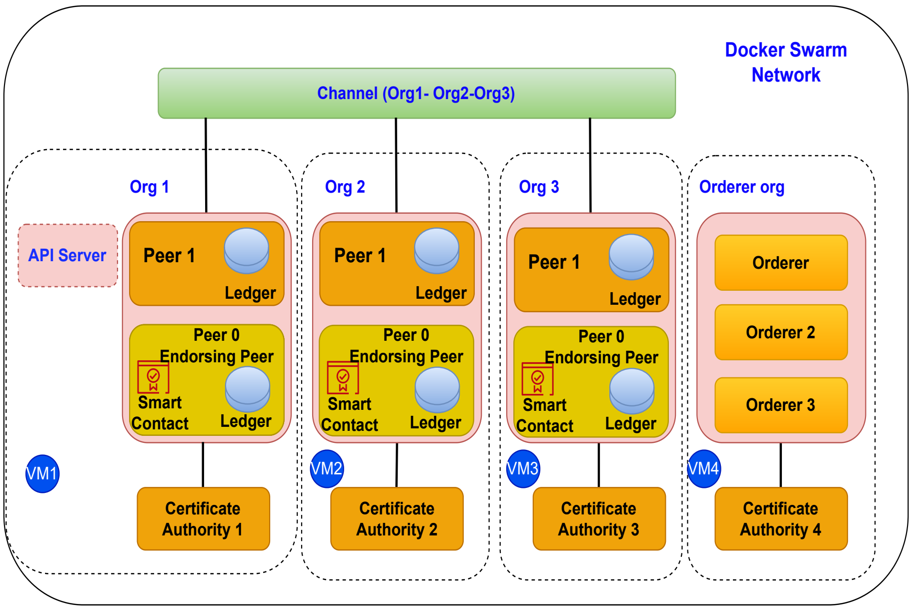


Figure 5.4: Architectural overview for the simulation environment.

For the analysis purpose, four(4) virtual machines were running on the VMware virtual platform. All four machines contained the same configuration as follows:

- 4 Intel(R) Xenon(R) Gold 5220 CPU@202GHz 2C2T.

- Ubuntu18.04 OS
- Hyperledger Fabric version 1.4 framework.

HLF deployed the underlay of the blockchain and used it for the simulation to implement the BC network. The system configuration had different components and dependencies. These include the Docker, which composes configuration, docker swarm setup, API servers, Chain Code configuration, external data storage, various network access, etc. To accommodate the edge IoT nodes, a shared Docker swarm Network was implemented. Docker composes and consensus-related algorithms are deployed, configured, and modified to test the HLF network. Figure 5.5 shows

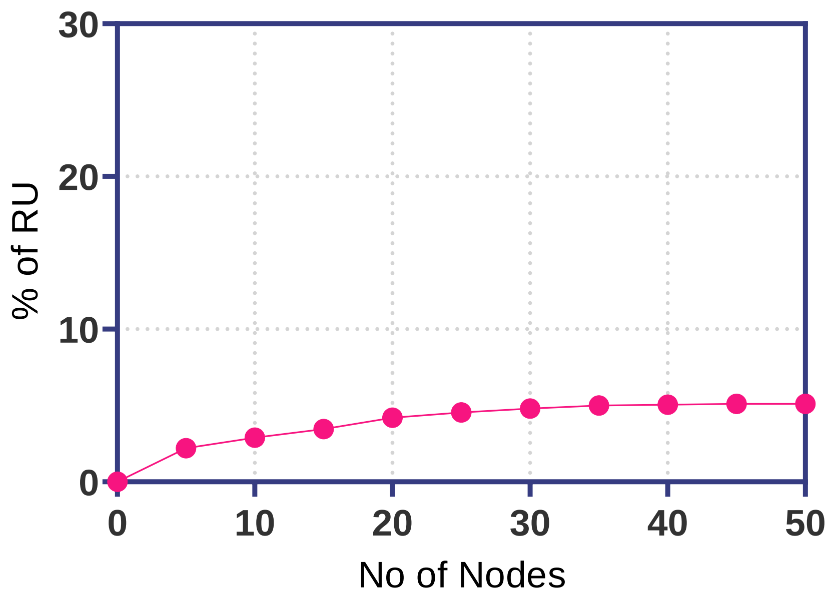


Figure 5.5: CPU utilisation transaction of the BC.

the resource utilization of the HLF Blockchain and CPU uses with the increased number of nodes in the network. When the number of nodes increased, the CPU uses increased. However, after 46 nodes, the allocated memory in the VM node peaked and remained stable. Though this memory usage was not caused by one node, it was distributed with the entire nodes. The RU should meet the requirement of the latency for a variable load.

The latency for different consensus algorithms was also measured for the order service. Figure 5.6 shows the latency for the different consensus algorithms. In the proposed model, the Kafka algorithm performs better compared with Raft. The Blockchain's decentralized nature reduces the latency as the decentralized network works as an individual node inside the network is independent in decision making. The node can perform the process and record the other node's transactions, reducing the network's load and latency. Kafka performs better than Raft. The result also depends on the CPU utilisation, capacity, memory size and number of nodes running at a time.

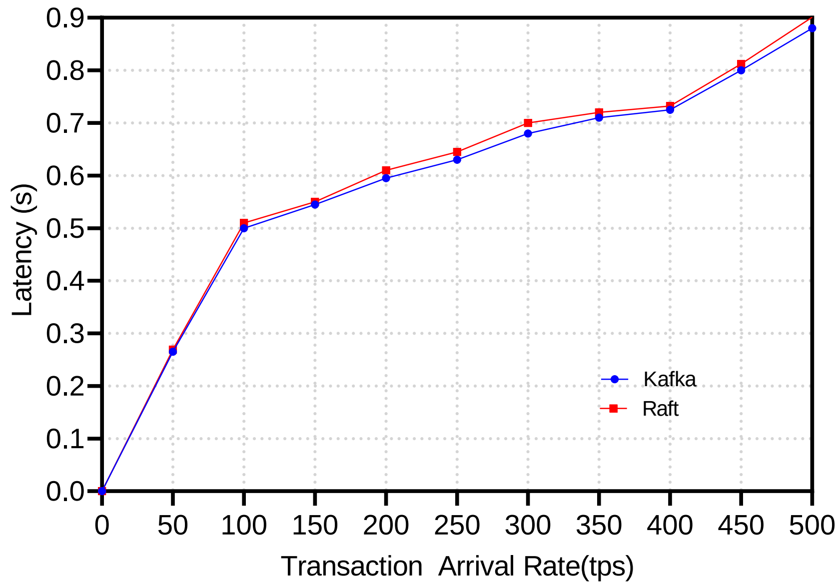


Figure 5.6: Latency for the different consensus algorithms.

The throughput by inserting the different transactions by varying the higher load was also measured. Figure 5.7 shows the transaction size concerning throughput. The result shows the exponential increase of throughput with the increase in the number of transactions. The throughput reached a peak with around 3600 transactions. From the figure, the maximum throughput can be achieved by filling the number of blocks and considering the large batch size of the transactions. As the system set up a virtual desktop in the VMWare environment, it cannot extend it from 60 transactions because of the limited capacity of the virtual desktop. The virtual machine needs to configure the allocated memory, and OS cannot allocate more than a specified memory for each program. The OS policy controls the allocated memory size.

The throughput performance of different consensus algorithms was measured and shown in figure 5.8, which can be used to define the security level, scalability, and transaction speed. From the figure, Kafka performs better than the other benchmark protocol, Raft. The throughput for the orderer service was measured, and it was found that Kafka performs slightly better than Raft for the order service.

Figure 5.9 shows the transaction response time, one of the disaster's crucial parameters. The response time increases with the increase in the number of blocks. The transaction was controlled by the peers and authorised by the orderer. As a result, the order has handled the transaction promptly at the beginning stage. With the increased transaction number, the response time increased as the transaction was

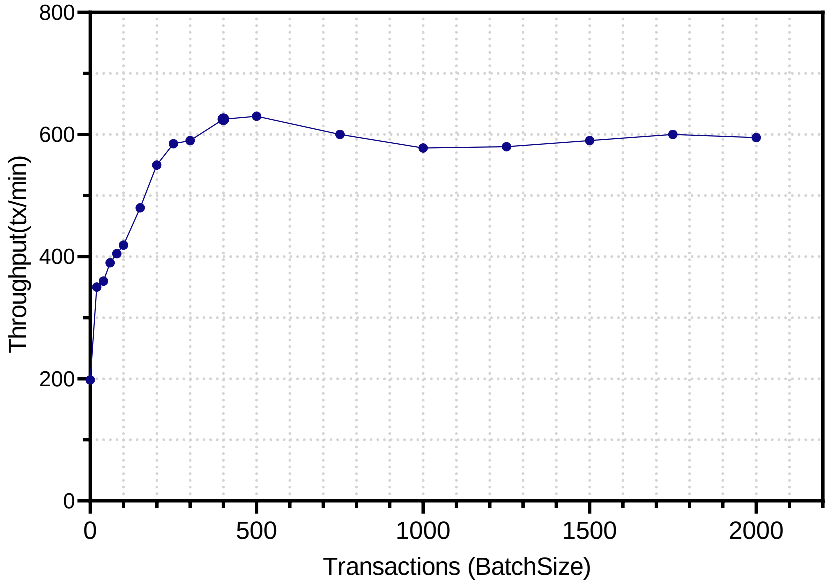


Figure 5.7: Throughput for the different block size.

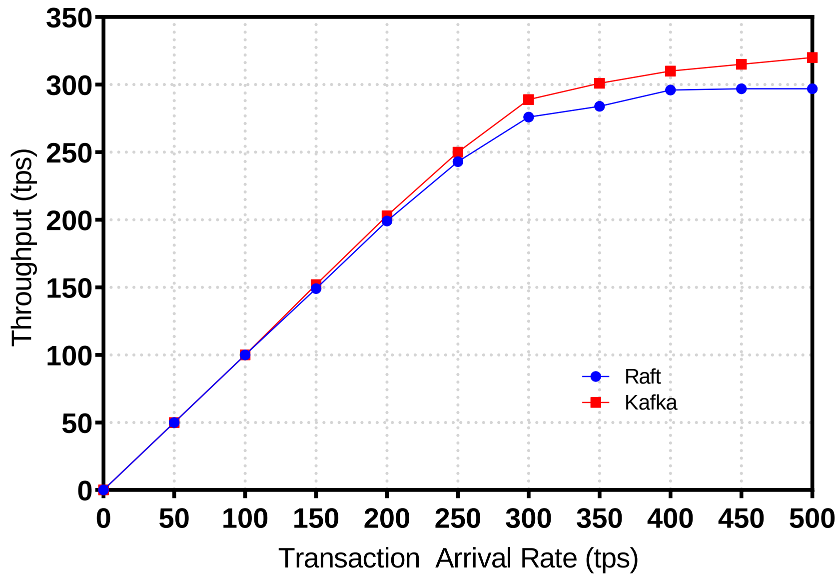


Figure 5.8: Throughput for the different consensus algorithms.

placed in the queue for verification and process. The result shows that the graph is nonlinear at the beginning, and the response time is meagre. However, the response time increases linearly when the transaction is placed in a queue.

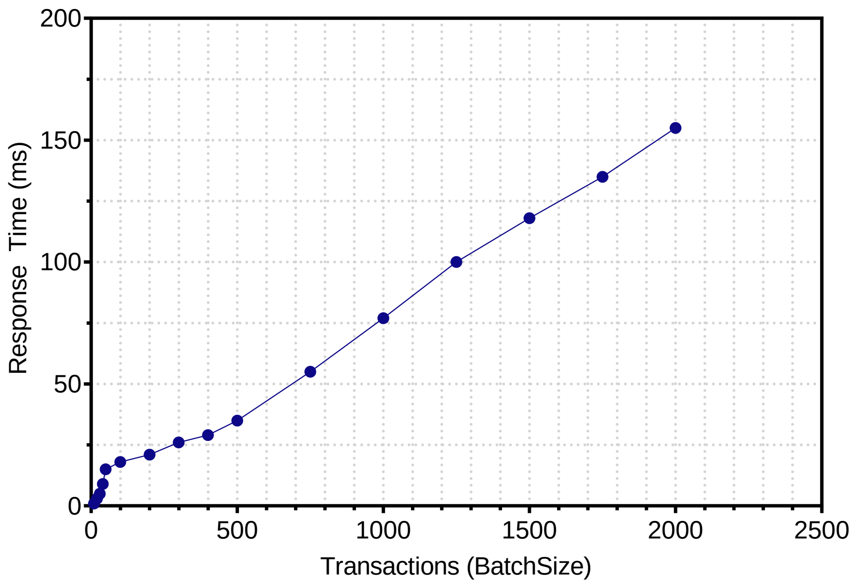


Figure 5.9: Throughput for the different consensus algorithms.

5.6 Summary

The communication framework with emerging technologies (IoT, D2D communication) can provide seamless connection, capture and deliver high volumes of data, extend network coverage area, and energy-efficient communication. These technologies have many security concerns, especially data security, user privacy, data integrity, and trust. Hyperledger Blockchain-based disaster architecture proposed in this chapter provides user authentication, authorisation, and validation to overcome security threats like eavesdropping, the free-riding of selfish peers, and can overcome the security threats of wiretapping. Thus, an HLF Blockchain is implemented in this chapter to evaluate the proposed system's performance.

Blockchain technology will be integrated into many fields to achieve digital convergence. The technology's distributed nature and its robust encryption system could solve different data security issues in D2D communication during a disaster. However, the secure data needs to be processed and analysed for prompt response. Data analytics and visualisation technique for the Disaster response system is discussed in the next chapter.

Chapter 6

Data Analytics and Visualisation for Disaster Response System

6.1 Introduction

This chapter aims to use Big Data technology to enhance the performance of disaster data storage and processing. For decision-making during urgent circumstances, machine-learning (ML) helps to decide about the disaster prediction when it strikes and the impact of the disaster. This chapter also establishes and compares the Deep Neural Networks (DNN), Support Vector Machine (SVM) and Long Short-Term Memory (LSTM) model performance to train and test the data. In addition, the performance of different storage systems such as Map Reduce and Spark is valued by the research community as a new generation technology for data processing, summarising and visualising the data for quicker response in disaster.

6.2 Background

Communication channel plays an important role in enhancing the performance of disaster recovery. Social media (Twitter, Facebook, microblog, etc.) become essential media for communication channels. The U.S.A. weather service declared that for the environmental information service, they will rely on Twitter after Twitter introduced a new service named Twitter Alerts [185]. The system is designed to prioritise information from the authorised agency. A similar service was also introduced by Facebook named Safety Check.

Mobile Users (MU) can build a stable social network by using the mobile social network. The MU exchanges data directly and integrates this data into the social network. This exchange data is used to enhance the data quality and enhance the

accuracy of social media information. The enhanced performance of the social network also influenced the performance of the D2D communication in the 5G network [186]. There are many applications built on the improved performance of social media based D2D communication especially emergency communication during disasters, proximity based social networks (location awareness).
The architecture of the social media integrated with the D2D communication showed in figure 6.1. It is divided into two parts: one is the social network layer and another is the D2D physical layer [187].

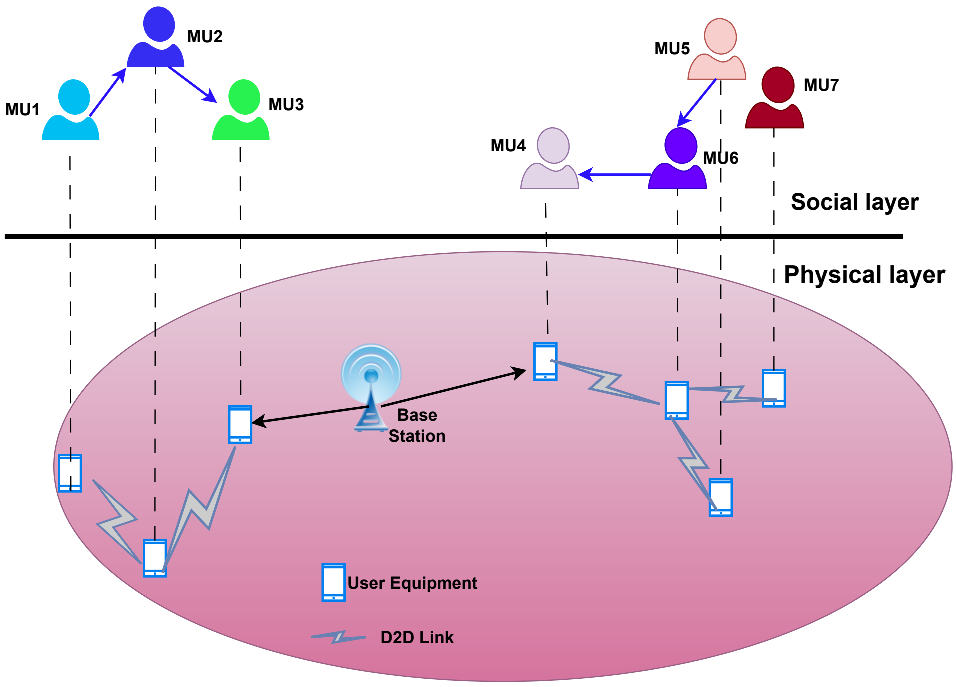


Figure 6.1: Architecture of social media based D2D communication.

The MU's activities is considered as a true social relationship in the mobile social network. The user's activities of the data collected from social platforms like Twitter, Facebook etc. are considered as proximity closeness of the user connection. The establishment of the D2D connection in the physical layer was detected by the distance of the two Mus. The user devices (Mobile, tablets, etc.) are used as the D2D device. The devices act as the Gateway of the network to exchange information. To successfully receive the message using a D2D link, both layers must be present for the neighbour discovery, cluster formation and data delivery.

In traditional D2D communication, peer selection or gateway selection are used two methods:

- **Ad Hoc Method:** In this method, the discovery of the peer devices are done using the distributed devices that transit the beacons periodically and select the nodes which transmit the signal strongly among all other peer nodes.

- **Network controlled:** In this technique, the peer discovers devices are selected via network controlled devices.

To establish the D2D communication, the UEs used a peer discovery algorithm to select the gateway users. The gateway users are used as the relay peer also known as CH in the D2D communication. The social network also used the same technique of peer discovery [188]. For the last few years, the authors are developing an algorithm for peer discovery in the socially aware method in D2D communication. The gateway node is selected by the mutual trust between two nodes in the social domain.

D2D communication mode selection and peer discovery is one of the critical factors in the establishment of the connection of D2D communication. The social network based social relationship can used to solve these problems by using the social traits. social media platforms can be used to discover nearby users with similar interests or goals, which can lead to the formation of D2D communication groups. For example, users can create Twitter groups or hashtags related to specific events, and then devices with D2D capabilities can use this information to connect with others in the same group. This social network ensures the fairness of the communication establishment and also ensures the quality of the service (QoS) of the D2D cooperative communication. The authors [189] integrated the online and offline social network to improve the traffic offload of the D2D communication. The offline users are used to make social relations and online users are used for the create the subgroup of the offline social network. This method improves both QoS and network traffic for the D2D communication. Twitter allows users to share content such as photos, videos, and messages. In D2D communication scenarios, devices can use D2D connections to directly share this content without relying on a cellular network, which can be particularly useful in crowded or congested areas.

It can be observed that traditional cellular-based sharing practices can be revolutionized through wireless D2D communication, eliminating the necessity for a base station. Through in D2D communication, multiple mobile users can exchange files, creating a "virtual" network of connections among users. The behavioural patterns and social characteristics seen in this offline social network are highly comparable to those found in online social networks. For example; Twitter can provide information about the proximity of other users who are also active on the platform. This information can be used by D2D-enabled devices to establish local communication links for various purposes, such as information sharing.

Cluster-based D2D communication is one of the important features which is used for the energy-efficient communication in disaster situations. The CH is also used as a relay device for communication with the Base Station. The selection of the CH is based on the significant degree of the parameters of the devices. The same concept is employed in social networking by aggregating devices into clusters, which is based on MU social link. The CH in the social network is selected using social ties to facilitate D2D communication. The highest tie between two nodes is selected as a Cluster head [190]. Devices can use location services to identify the proximity of other users and establish D2D communication links. It is very useful to make announcements or coordinate D2D communication activities. For instance, during a disaster or emergency situation, Twitter can be used to disseminate critical information and instructions, and devices can use this information to establish direct communication links for coordination and assistance.

However, getting the data from crowdsourcing in social media generates a massive amount of unstructured data. To handle the high volume of social data, there is much research that exists for the different big data applications [191, 192]. One of the critical challenges for data collection and processing in the system in disaster response is the establishment of the communication network after a large or mid-scale disaster strike. The author[193] proposed an Adhoc network and smartphone-based emergency communication to overcome network resilience.

One Big data application is for disaster damage assessment. It uses different data sources, and the entities define the damage caused by the disaster. It gives a clear picture of the response's priority task and avoids the responder duplication task. The author[193] discovered the integration of the crowdsource data or the social media data with the device sensing data, for example, satellite or UAV. This collected data will ensure the user data's accuracy and enhance the response system.

For data source, social media platforms like Twitter, Facebook, and Instagram play important roles. Many researchers have discussed the importance of social media integration for data circulation and gathering [194]. Social media can play a part in all four stages of disaster management by helping the disaster preparation through getting disaster warning information, and by giving a clear picture of the percentage of damage and emergency help needed after the disaster[185].

Other studies [195, 196]investigated the key challenges of data management methods: data integration and cleaning, information retrieval, information extraction, information filtering, decision support, and knowledge-based systems in catastrophic events. The author[197, 198] proposed a data mining technique for the disaster response. This uses disaster prediction and detections from the social data sources. From the social platform data, the authors developed the strategies of the disaster system by analysing blogs and text messages[199]. The author [118] reviewed the proposed big data technologies are primarily used in actual natural disasters during the response phase. In addition, Big Data and social media tools are used for client's databases and general disaster management software. The first aid responder, Government and non-government organisations are the key stakeholders of this system to get precise and accurate information during the disaster response phase.

6.3 Proposed Model

The study designed a Big Data computing framework to analyse the text according to the priority of disaster-affected people, when communication channel establishment, data collection and data processing are the biggest challenges in a post-disaster situation. Because of damage of the communication infrastructure, disaster-affected people are not able to communicate their real needs to the first responders. Cluster based D2D communication can solve this problem in the absence of BS as D2D communication does not depend on the BS. However, it is also required that there is a framework that will receive the massive data from different sources in the disaster area, process them and provide real time needs of disaster-affected people. This framework will help the first responder know about the response and recovery plan after disaster.

The framework is divided into two parts.

Part-1 Part 1 includes the selection of a high efficient machine learning model that will be able to analyse the data more effectively and efficiently. Figure 6.2 shows the flowchart of the design model of par -1. The first section is divided into three parts.

1. Data collection and processing.
2. Computing Environment.
3. Modelling and Evaluation.

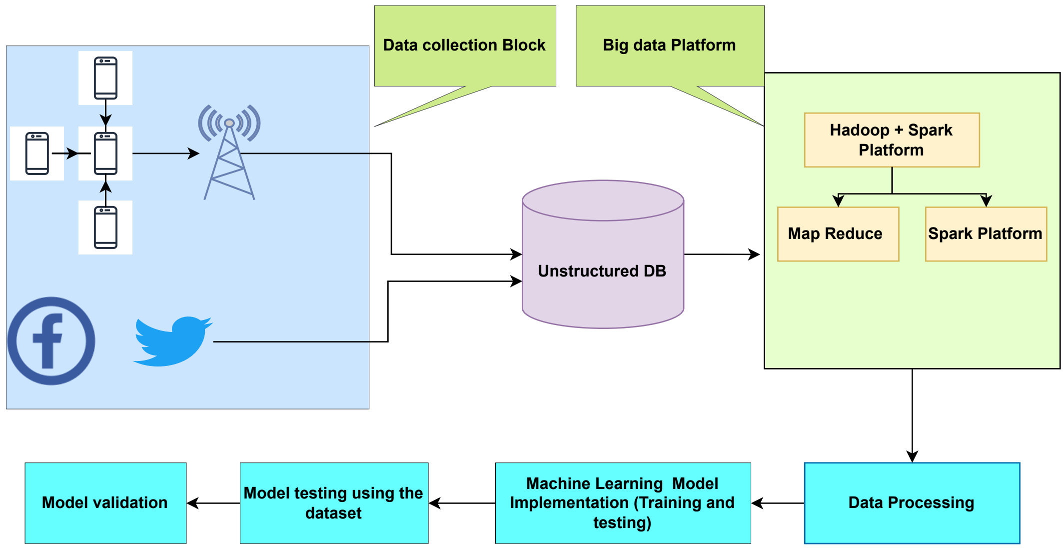


Figure 6.2: System Model design flow for model selection (part-1).

Part-2 Part 2 of the framework includes the unstructured data collection from disaster areas, storing and processing in the Big Data system, applying the selected machine learning model, classifying them and sending accurate information to an interactive dashboard. This information, can be processed by the first responders into their response plan.

The process of part 2 is shown in figure 6.3 it assumed that after the disaster strike, the UE can communicate via Device-to-Device (D2D) technology using clusters under a 5G network. After a disaster, D2D is the faster communication media available as these can communicate without the help of a Base Station (BS); D2D communication can send emergency text messages during a disaster[200]. The architecture of the D2D communication integrated with the social media is discussed in the previous section. Cluster formation and communication link establishment is presented in chapter 3 of this thesis. It is assumed that one of the realy device is connected with the mobile network operating under the fifth Generation (5G) cellular systems, as 5G consists of radio access network (RAN), core network (CN), and user equipment (UE). 5G included in a multiple base station (micro cell, Pico cell, femto cell, etc.) can randomly access different networks, which are known as RAN. CN includes numerous service-based network systems and UE is the normal node, meaning a mobile phone [201]. As 5G consists of services-based architecture, it is very flexible, highly efficient, and has scalable network which can play a crucial part during the disaster period.

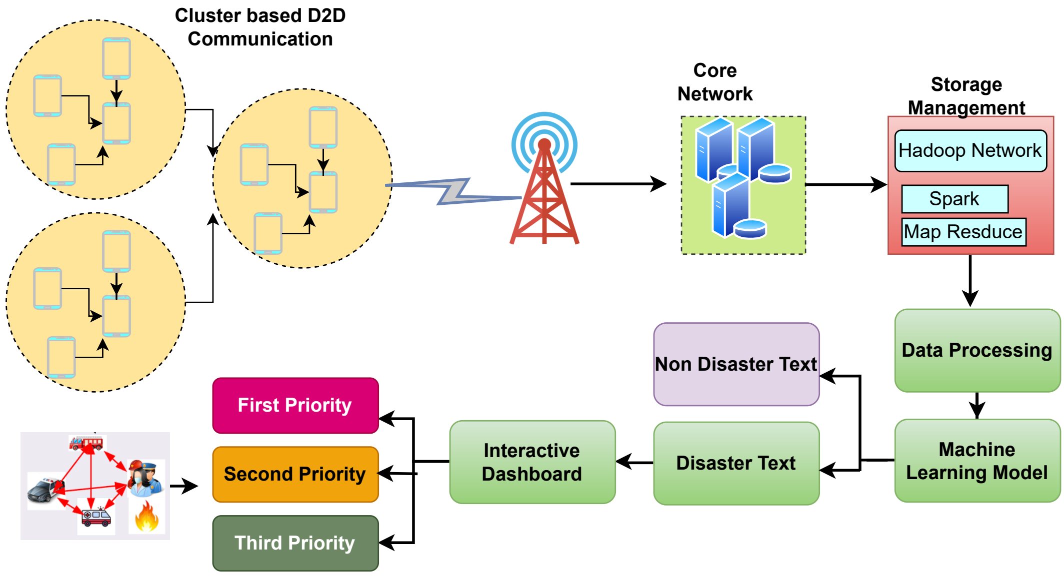


Figure 6.3: System Model design flow chart for model selection (part-2).

6.4 Model Validation

To validate the proposed model for data collection,Raspberry Pi based IoT was used as a D2D communication device. Two Raspberry Pis communicate with each other directly without an Wi-Fi or mobile base station connection. Figure 6.4 shows the system model of D2D communication.

Two devices establish the connection through a python script which is installed on the devices, and communication is made with the help of a wireless adapter. Wi-Fi direct is used for the communication protocol, and this protocol determines the device distance and communication speed. The python script scans for neighbouring devices with the same communication protocol. Once the device detects them, it establishes the connection and sends the data packet to the connected devices.

There is another raspberry pi which acts as a gateway to the BS. As the raspberry pi did not support most router software, OpenWRT are used to configure raspberry pi. This gateway device collects data from the local device and stores it via the cloud for further analysis.

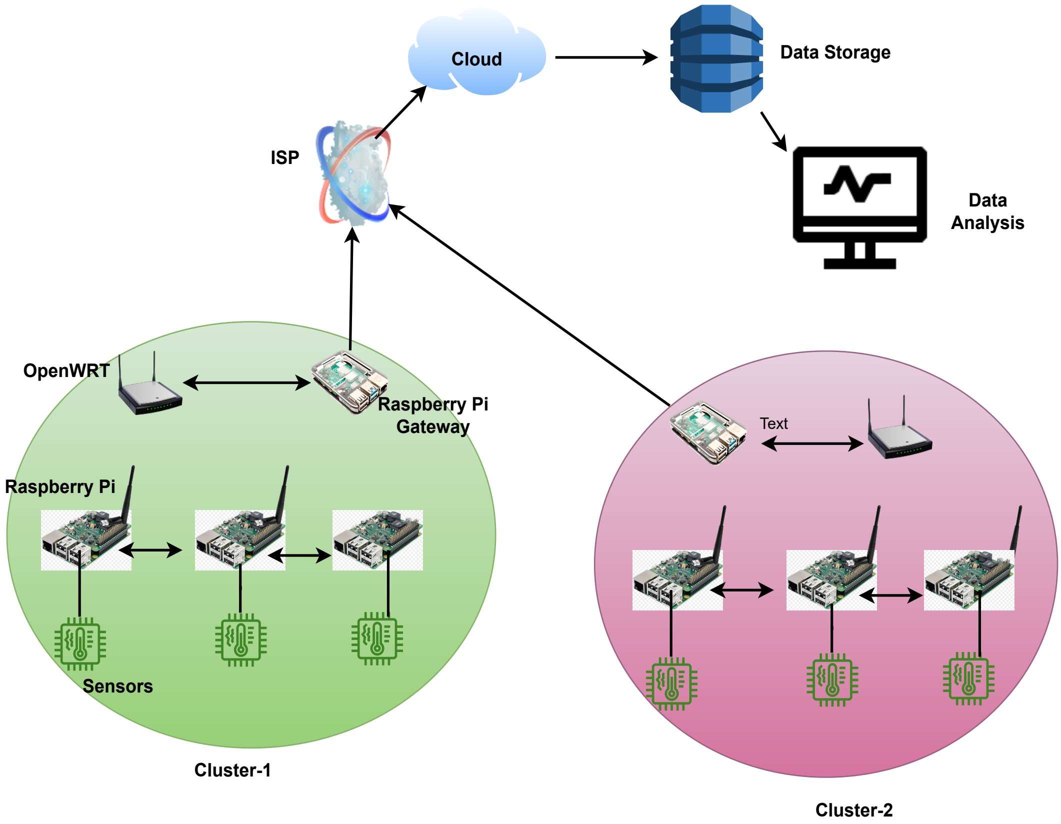


Figure 6.4: Validation of the proposed model for the data collection.

6.5 Data Collection and Processing

Twitter data were used for model training. Twitter is one of the popular social media platforms. Disaster-related Twitter data were collected from the third-party vendor *Followthehashtag* http://www.followthehashtag.com/. The keywords from the Christchurch earthquake, Nepal earthquake, Florida hurricane, Haiti earthquake, and Japan tsunami were collected and used. The priority service, category and keyword used to predict the disaster class are given in Table 6.1.

Table 6.1: List of the keywords for the disaster.

Priority	Category	Key word
1	Medical emergency	Medical, Medicine, hospital, clinic, GP, Doctor, Nurse, tablet, first aid.
2	Water	Water, clean water, drink water, tap water, thirsty, drink
3	Food	Food, hungry, dinner, bread, egg, jam, cereal
4	Accommodation	House, flat, shelter, rest, sleep, bed, duvet, pillow
5	Other	Police, security, power, electricity, phone, light, heat pump, heater

Data were generated according to different disaster scales using table 6.1 keywords. For generation of the text message, it was assumed that these generated data are collected by the Cluster-based D2D communication under 5G mobile network, the pseudocode of generated data according to the disaster scale. The generated data integrates the location coordinates (longitude and latitude) features. This feature used in Part 2 of the design model also help to demonstrate how the responder can use the visualised dashboard during the response.

Algorithm-4 shows the pseudocode for the cluster formation and data generation of a node. The model considered 10 CHs in three different locations. 10 CHs consists of 10 different files which merged and stored in the Hadoop system.

Algorithm 4 Pseudo Code for the data generation of a node.

Initialize the random location from a longitude and latitude range
Place Cluster Head (CH) in a random location.
Every CH creates a file
Place normal node in random location which is not same for the CH.
Calculate the distance of each node with respect to CH using the below Haversine distance calculation formula.
$A = \sin^2(\frac{\alpha}{2}) + \cos\alpha_1 . \cos\alpha_2 . \sin^2(\beta_2)$
$B = 2.\,\text{atan2}(\sqrt{A}, \sqrt{(1-A)})$
$C = R.B$
Where, α is the latitude, β is the longitude and R is the radius of the earth.
Select the CH's of each node, which have minimum distance between node and CH.
if the distance $\geq$100 m; consider node as an individual node.
Use python function to generate the data for each node.
Every node data will save in that node's CH file.

Total tweets from these data were classified, then 80% of these data were used for the training model, and 20% were used for the test and evaluation of the model.

6.6 Algorithm Selection

Machine Learning (ML) models were explored for the classification of text according to the performance indices of an ML model. For the text classification, there were a number of machine learning used. However, Support vector machine (SVM), Deep Neural Network (DNN) and Long-Term Short Memory (LSTM) were used for our work.

6.6.1 Support Vector Machine (SVM)

SVM is one of the popular ML algorithms for the classification problem introduced by the Vapnik et al based on the statistics learning theory. SVM is used for the small dataset, non-linear and high dimensional problems [202]. The main concept of the SVM is to develop a hyperplane that is used to separate two classes of data. The maximum distance between two classes points on the hyperplane and the separation margin is known as a decision surface. Let us consider the two classes of data from a classification problem where training set $x_i, y_i, i = 1, 2, 3, \ldots, n.x_i^d, y_i 1$. SVM binary classifier develop the optimal separating hyperplane by using $H : A^T x + Z = 0$ in the features area where A is the dimensional vector and Z is a real number.

6.6.2 Deep Neural Network (DNN)

A Deep Neural Network (DNN) is a collection of neurons which are organized in multiple layers[203]. The neurons receive input by the activated neuron from the previous layer. After receiving the information, the neuron performs a simple calculation. Each of the layer input is the output of the previous layer and progresses to the higher level of features which creates a complex nonlinear mapping from input to output. This map learned from the input data by taking the weight of each neuron. Let us consider a DNN classifier mapping data points x to a set of classes $(\omega c)c$. The modelled class probability of the out neuron is $p(|x)$. A prototype x which represents a class ωc can be found by:$(max) log P(\omega_c x) - \gamma v|x^2|v$. Figure 6.5 shows the DNN model.

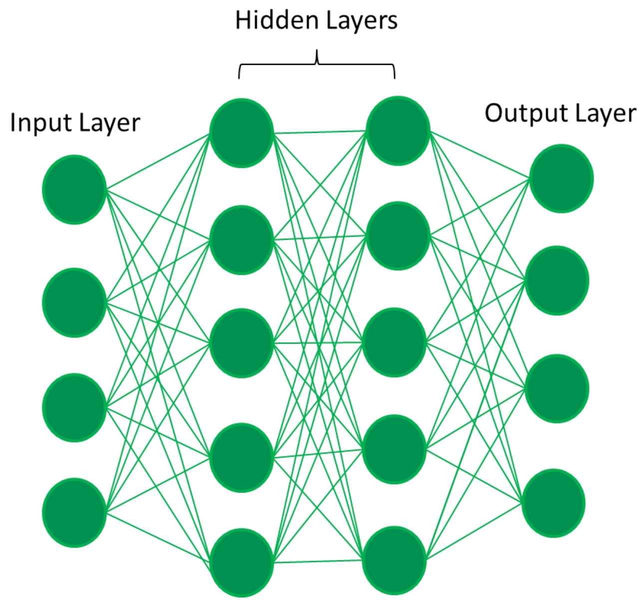


Figure 6.5: Architechture of DNN model.

6.6.3 Long Short-Term Memory (LSTM)

Long Short-Term Memory (LSTM) is one of the parts of Recurrent Neural Networks (RNN). LSTM Cell are used as nodes in RNN[204]. This cell consists of extra gates known as input, forget and output gates. The output gate decides which signal will move forward. Figure 6.5 shows a LSTM cell in which there are extra gates, the input, forget and output gates, that are used to decide which signals are going to be forwarded to another node. Figure 6.6 shows the LSTM architecture.

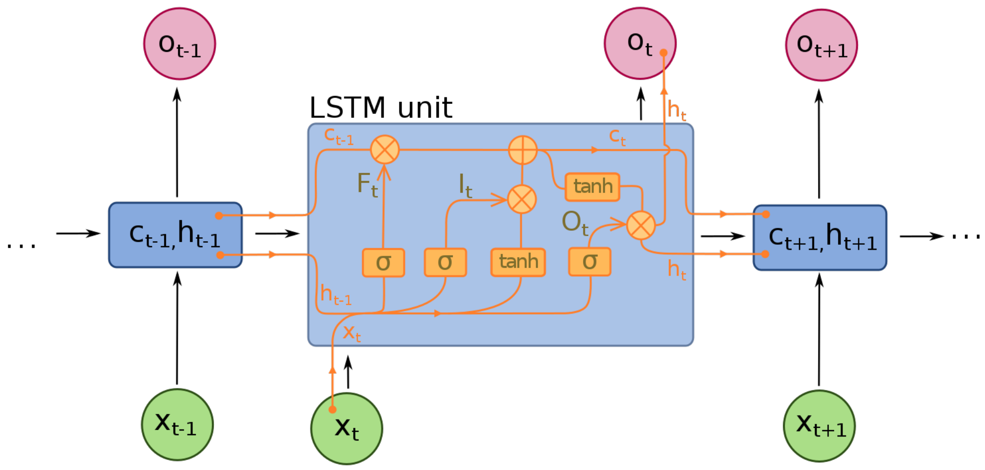


Figure 6.6: Architecture of LSTM model.

$$i_t = \sigma(x_t U^i + h_{t-1} W^i)$$
$$f_t = \sigma(x_t U^f + h_{t-1} W^f)$$
$$O_t = \sigma(X_t U^0 + h_{t-1} W^0)$$

$\overline{C}_t = \tanh(x_t U^g + h_{t-1} W^g)$
$C_t = \sigma(f_t * C_{t-1} + i_t * \overline{C}_t)$
$h_t = \tanh(C_t) * O_t$

Where, W is the recurrent connection, U is the weight matrix, $\overline{C}$ Is a candidate-hidden state, C is the internal memory unit. W is used to recurrent connection between the current layer and previous layer. U is used to connect input to the hidden layer. In the hidden state computation done on the current input and previous hidden state. The internal memory unit is combination of the previous memory multiplied by the forget gate and $\overline{C}$ multiplied by the input gate.

6.7 System Description

Big data technology used to process, store, analyse, and extract insights from the large and unstructured data. Hadoop and Apache Spark are two prominent and complementary open-source frameworks used in the field of big data for processing and analysing large datasets. Both system is used to measure the performance for the disaster related data.

Apache Hadoop- The Apache Hadoop [205] is an open-source software framework that allows for distributed processing. The Hadoop system is administered by Google architecture. It has the capacity to store Terra Bytes (TB) size of data and live streaming data. This software library has the capability to store a large data set across the cluster. The system is designed in such a way that it can integrate from one machine server to a thousand of machines, each of which has a local storage system and processing capabilities[206]. The software uses the parallel processing of a large data set and has the ability to produce information, which is very important in the case of analysing large scale disaster data. Figure 6.7 shows the architecture of the Hadoop system.

There are two main core part of Hadoop system, 1. Hadoop Distributed File System (HDFS), and 2. Map Reduce.

HDFS[207] is a distributed file system that extends from single to multiple servers. Figure 6.8 shows that the HDFS system uses the name node, also known as the Master node, responsible for the HDFS directory system reading and writing the data. The other nodes, known as data nodes, are used for the storage system [208][209]. HDFS is designed to read and write the live data and process a large set of data very fast, as it splits the larger file into small pieces of block and saves it in the data node[210].

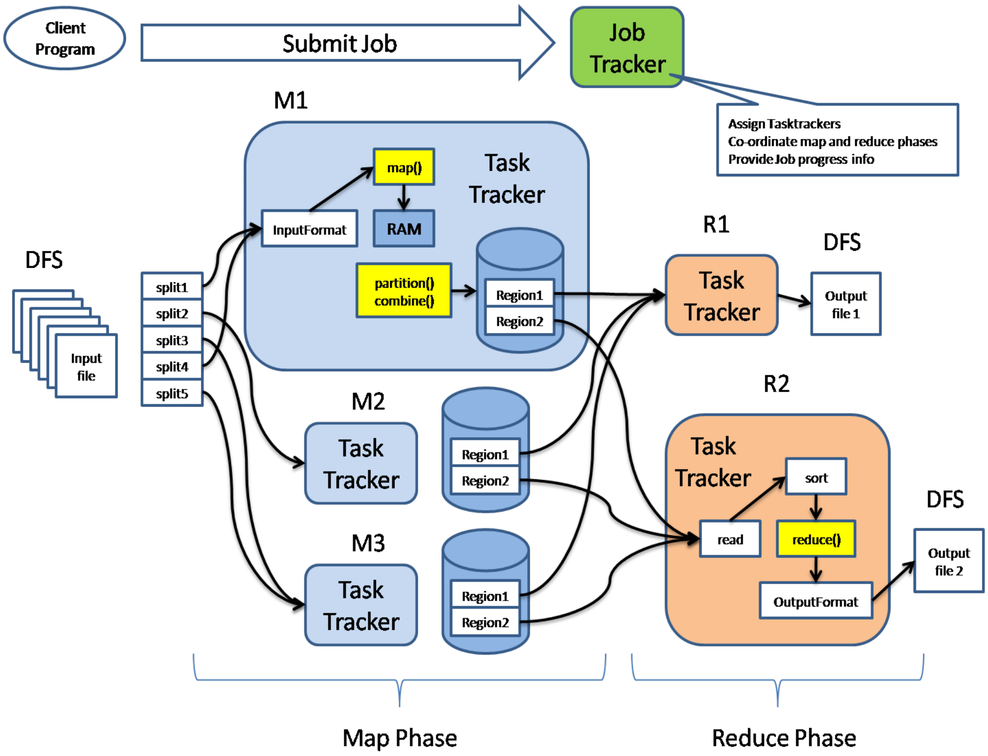


Figure 6.7: Hadoop Architecture.

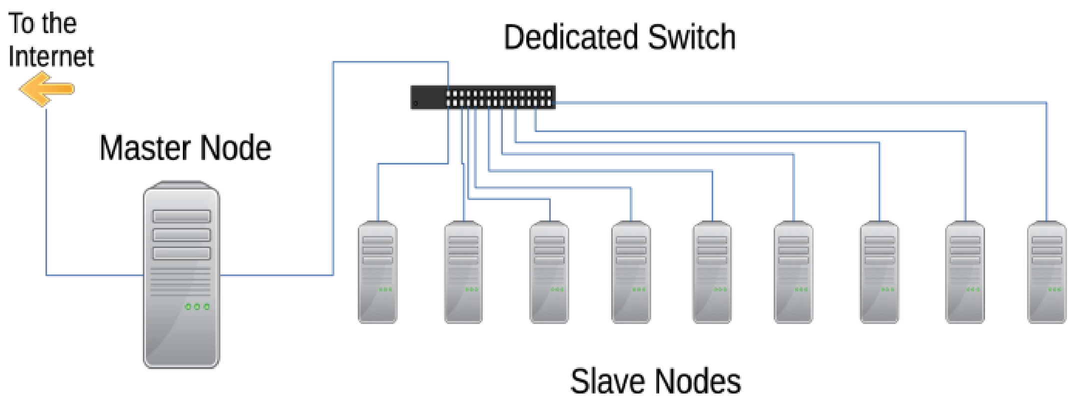


Figure 6.8: Top view architecture HDFS system for the Hadoop.

Map Reduce [211] is a parallel computing framework that is divided into two parts, Map and Reduce. Figure 6.9 shows the Map Reduce system. The map section divided the file into subfiles, implemented by separate multiple data nodes. Reduce sections added all the data nodes, integrated all the processed data in the data node and produced information and results that were sent back to the master node.

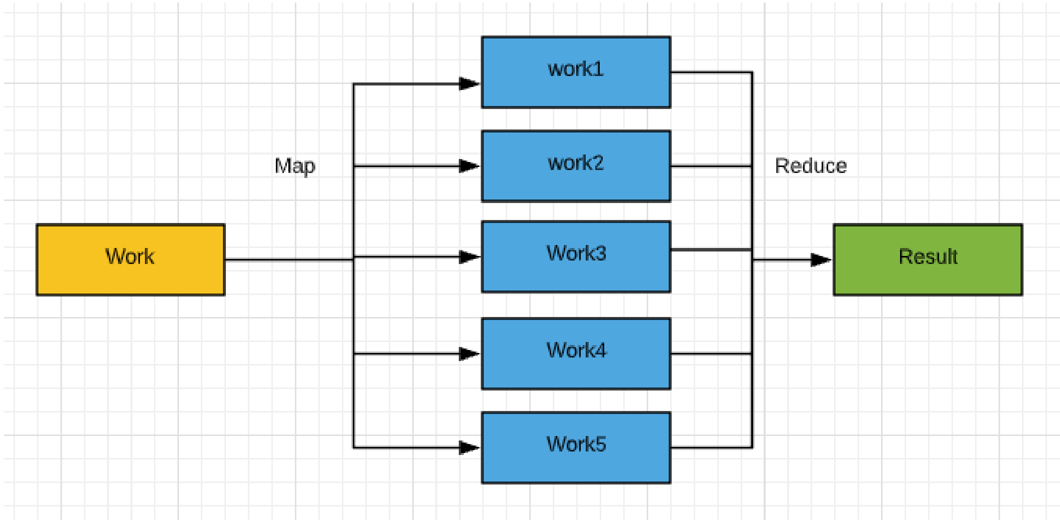


Figure 6.9: Map reduce for the Hadoop system.

In addition, the map-reduce routine can be customised for analysis and can examine the unstructured data across hundreds of nodes. It transforms the large dataset into a management dataset, splitting a large amount of data into small manageable chunks of data; after which, it maps the splits accordingly[212]. The number of a split chunk of data is stored on a distributed cache for the subsequent operations. The operation is managed and maintained by two nodes. A) Name nodes B) Data nodes. Any file system, size, location, type, and other attributes that changes or alters is recorded by the nodes. Primary data is also stored in the data nodes. The delete of the block HDFS or files is recorded in the edit log system, which too is stored in the name node. Based on the decision from the name node, Data nodes create, delete, or copy the chunk. The entire process manages and maintains the YARN (Yet Another Resource Navigator) which is a large-scale distributed operating system. The resource manager and node manager control this YARN. The primary function of the resource manager is to manage cluster-level components, which are run on the master computer. Further, the node manager manages node level components which are used to monitor the optimisation of resource utilisation and maintain the log file.

Apache Spark- Apache spark is an open-source unified analysis engine for large-scale data processing[213]. It provides an interface for customisation of the cluster by using programming and a parallel data processing engine like Map Reduce. However, Spark can data share abstractions. To process the wide range of workloads, Spark uses Resilient Distributed Dataset (RDD), which has the capacity for data sharing and automatic recovery from failure known as lineage. Unlike with third-party processing software like SQL, streaming with Spark uses RDD; the storage and processing time is much faster in Spark.

Apache Spark also provided some additional library space which is used for the high-volume streaming data process. Spark streaming also processes the real-time streaming data providing higher throughput and less processing time. It performs several operations like memory management, schedule task, monitoring task, fault recovery etc[214]. Spark SQL is the new module of Apache Spark, which is integrated with the functional program for relational database processing. This overcomes the drawback of the traditional Relational data processing system. In addition, GraphX, another exciting feature of Apache Spark, is used for the parallel process and provides API for graphs. It enhanced the performance of RDD by providing the graph properties, including creating the details of nodes, vertex and edge of the graphs. For the machine learning and artificial intelligence system, Apache Spark uses MLiB functions.

Hadoop Framework vs Apache Spark Both Hadoop and Apache technologies are used to analyse raw data. However, based on their architectural characteristics, they have differences in their performance. The literature shows that the iteration number in Spark is much less than in the Hadoop framework. The same result shows when machine learning is applied as expected, as most ML algorithm works respectively[215]. Spark uses Mesos, which executes the number of iterations on the dataset, and helps Spark to get a better result. On the other hand, Map Reduce uses a complex core-grained task that puts more weight on the iterative algorithm, making it slower compared with Spark. As there is some difference between both systems, they compete with each other. Map Reduce is the most economical solution for batch processing, which is also used commercially. Spark is used frequently for data streaming and distribution processing. Integrating the low-cost system Hadoop with the high processing speed and numerous integrational functionalities in Spark would provide excellent results in any domain, especially disaster management.

The experiment was conducted in the Massey University Hadoop cluster system. The cluster consists of 1 Name node, and 9 data nodes shown in Figure 6.8. The cluster consists of 80 CPU cores and 60 TB local storage[216]. The detailed specifications of the hardware and software are given in Table 6.2. This configured hardware can perform both Spark and MapReduce for a large and complex data set.Yet Another Resource Negotiator (YARN) was used, which served as a resource manager and job scheduler. This would monitor all the data node-processing states and track the details of each processing node.

Table 6.2: Configuration of the Hadoop system.

Server configuration	Processor	2.9GHz
	RAM	64GB
	HDD	10TB
Node Configuration	CPU	Intel(R)Xeon(R) CPU E3 1231 V3@3.40GHz
	Total core	10
	RAM	32GB each
	HDD	6TB each
	CPU core	8 each
software	Operating system	Ubuntu 16.042
	JDK	1.7.0
	Hadoop	2.4.0

6.8 Performance Matrix

To validate the performance of the selected ML technique, the following performance metrics was used for the classification problem for the disaster text and non-disaster text based on the literature:

$Accuracy = \frac{(TruePositive+TrueNegative)}{TotalSample} X100$

$Precision = \frac{TruePositive}{(TruePositive+FalsePositive)}$

$Recall = \frac{TruePositive}{(TruePositive+FalseNegative)}$

$F1-Score = \frac{(2*Precision*Recall)}{(Precision+Recall)}$ Where True Positive is the prediction of Yes and the actual output is Yes.

True negative is the prediction is No and the actual output is No.

False Positive is the prediction is Yes and the actual output is No.

False negative is the prediction is No and the actual output is Yes.

6.9 Results and Discussion

The part of the work implemented the Machine Learning DNN, SVM and LSTM models to train and test for the data accuracy. The performance of Big Data technology was measured for the different scales of disaster. The ML algorithms used for data classification from social media messages and predict the priority of the needs. The algorithms tested with randomly generated synthetic data for the different scales of disaster. The data prepared for the visualisation and the priority location set in the Google map. Python programming language used with various library functions: open-source library Tensor Flow. For the model and tuning, Keras Tuner was used. This study compared three machine-learning algorithms for the classification of the disaster need and non-disaster text. However, before the training and testing, cleaned the data by removing special characters and NULL values. Lemmatization was used to clean the data, which is a kind of process that helps to group the different modulations of a word. This helps to group all the different words into a single word. After cleaning the data, it was found that the average word of the social media tweets is between the ranges of (5-8), as shown in Figure 6.10. On the other hand, the average length of the non-disaster texts is between 4-10.

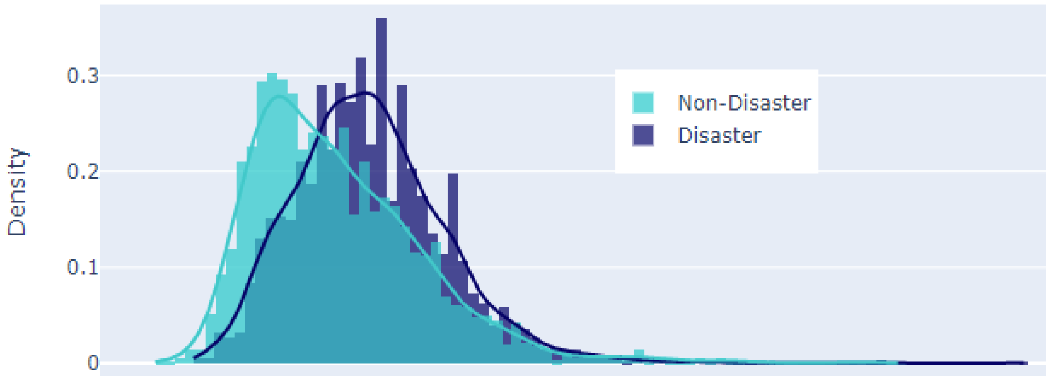


Figure 6.10: The density or the average word count for the disaster and non-disaster data.

Accuracy result is one of the key elements to measure the efficiency of any machine-learning algorithm. A major problem with accuracy is that the accuracy score usually becomes higher for the training dataset than the actual unseen test dataset. To overcome this problem, validation of a model is important and K-fold validation was used to estimate the performance of an unseen dataset. In the k-fold validation process, the dataset is divided into k parts. During each iteration part, the model was trained on the k-1 part and validated on the left 1 part. Finally, the average score of k estimates the value, which is more accurate than the value of the just training performance of data. For this model, the K-fold value as 10 was used to measure the best accurate result for our model.

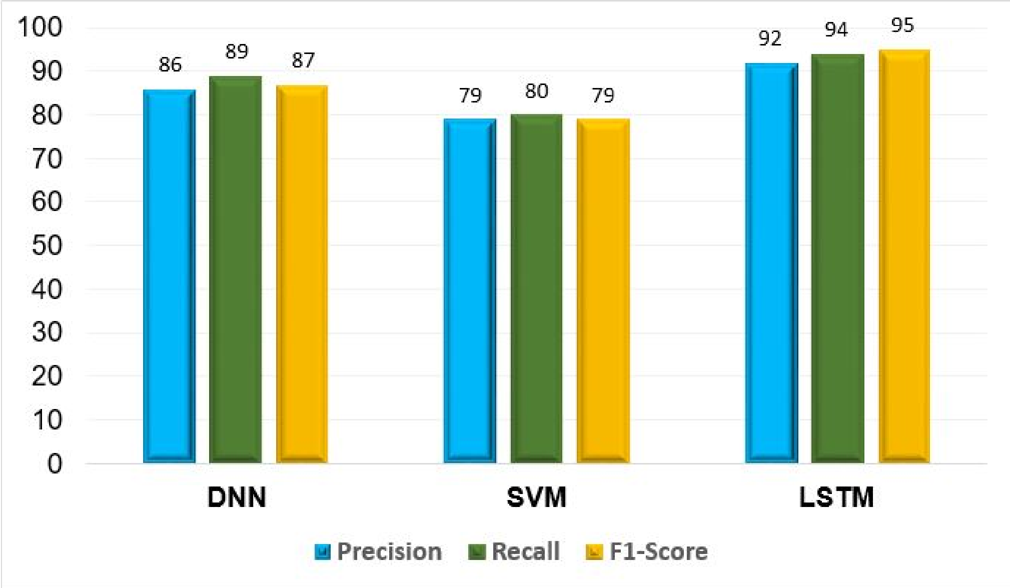
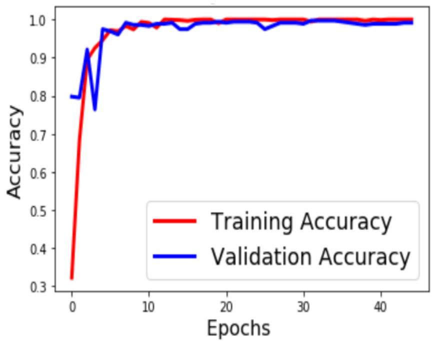


Figure 6.11: Precision, Recall and F1 score value for the DNN, SVM and LSTM.

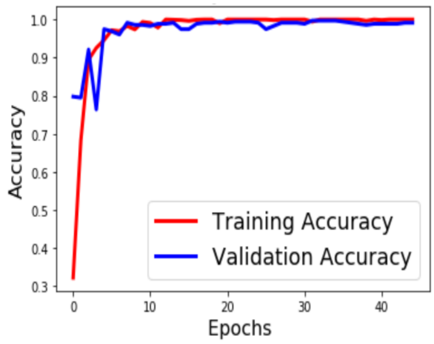
Figure 6.11 shows the precision, recall and F1 score for the models. The precision values are 86%, 79%, 92% and the recall values are 89%, 80% and 94% for the DNN, SVM and LSTM respectively. From the above figure, it is clearly visible that LSTM performs better than the DNN and SVM. The reason for this is that DNN is trained on multiple words taken as separate inputs and, while it is predicting the class, it will give the output according to the statistics, not according to the actual meaning of the text. However, LSTM uses multiple words to find which class the word belongs to. LSTM provides more accurate output classes when using appropriate layers of embedding and encoding.

Learning curves help to identify how effectively a model performs with the additional training dataset. The DNN model reached a training accuracy of above 90%; however, the validation accuracy is below 90%, a validation loss of 0.05 after 20 epochs but the training loss was nearly 0. On the other hand, in LSRM the model performed very well compared with the DNN model. Training accuracy and validation accuracy was nearly 100%. Training loss and validation loss performed equally as expected. Fig 6.12 shows the LSTM and DNN training accuracy, validation accuracy and training loss and validation loss graph.

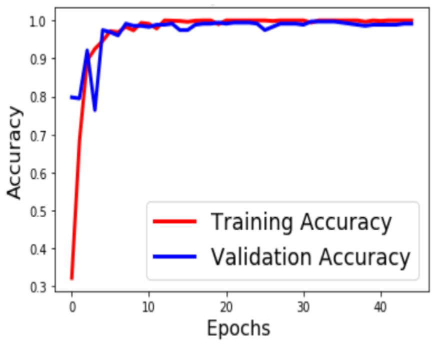
LSTM model selected for further testing and validation for the computer-generated synthetic data, which is Part 2 of the proposed model. Computer-generated synthetic data are divided into two disaster scales, large and small. For large-scale disasters, the area is big, and the impact of the disaster is high. These large-scale disasters will also generate a high volume of data. For the experiment, the text generated concatenation data of about 50GB. For the small-scale disaster, the data split into 10 parts; each part consisting of 5GB of data. The one 5GB split data is



(a)



(b)



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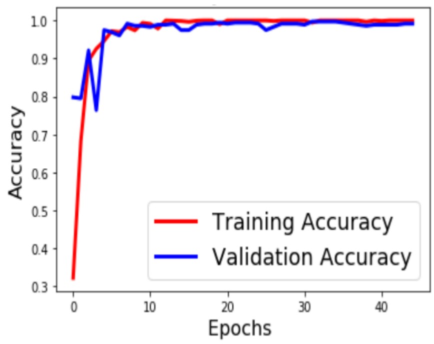

(d)

Figure 6.12: Accuracy for the LSTM and DNN.

considered as the small scale of disaster data. The ID, location information (longitude and latitude) and the message (Text format) are selected as the parameters of the synthetic data. Figure 6.13 and 6.14 shows the small-scale data category for the small disaster (5GB) and large-scale data category for large disaster data (50GB). These two datasets were stored and processed in both the Hadoop and the Spark systems. The dataset was run through the LSTM model for the classification and only disaster-related data was sent to the dashboard for visualisation.

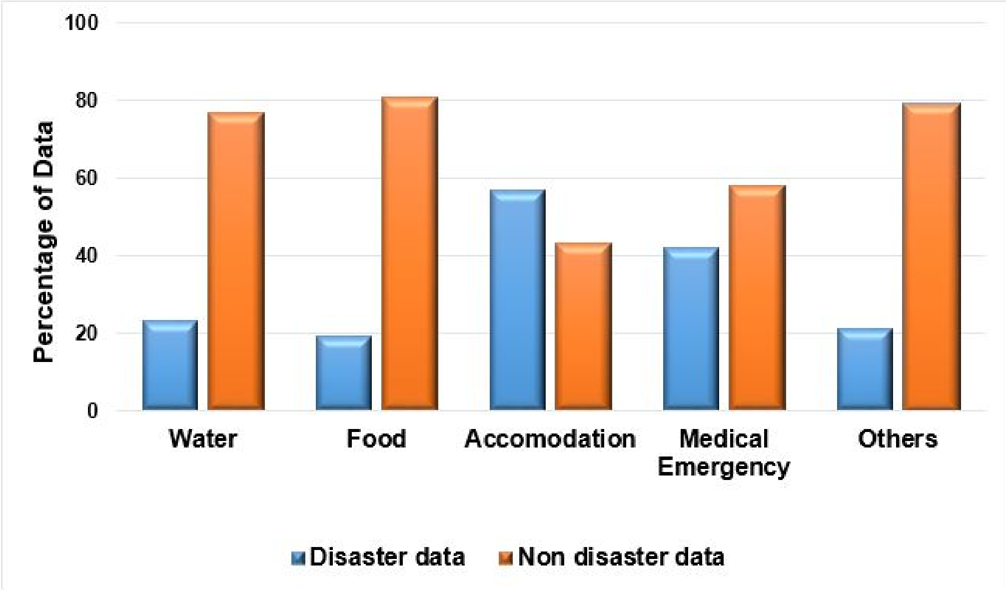

Figure 6.13: Small scale disaster data classification.

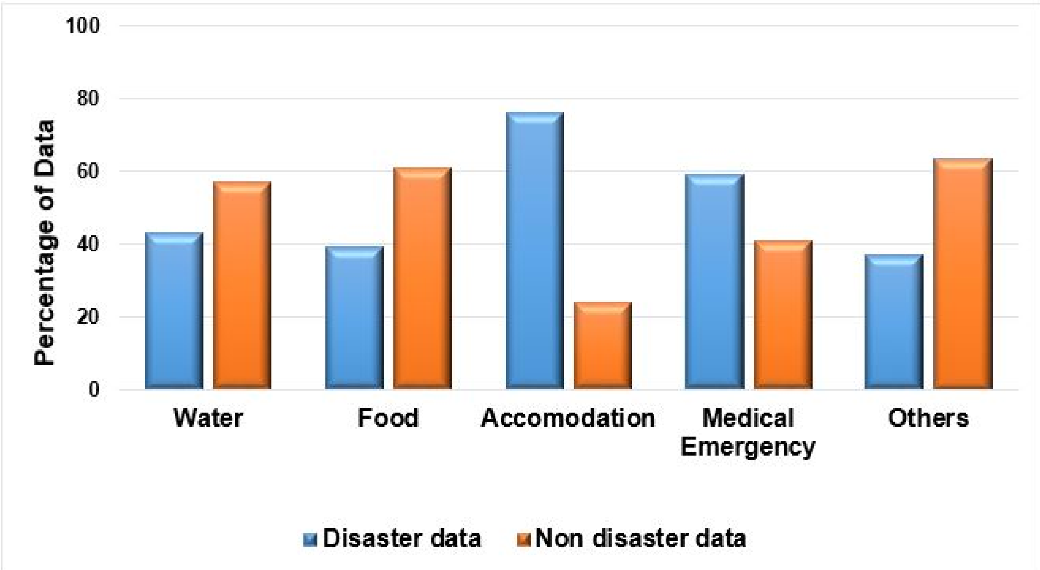

Figure 6.14: Large-scale disaster data classification.

For the data visualisation, the Google Maps layer are used. Figure 6.15 shows the heat map according to the needs of the disaster people. The first responders will get the information about the disaster that affected people need. Based on their needs, the responders will be able to make a priority of the task. The system will get exact information of the location where people need help and what their needs are. The responders will be able to make the plan properly without any duplication.

Figure 6.15: Large-scale disaster data classification.

The performance of both the Hadoop and Spark systems are measured in the disaster data to validate which system performs well for large scale disaster datasets. The results show in figure 6.16 that the Spark system performs well compared to the Hadoop system. With the increased size of data, the Spark system still performs better than the Hadoop system.

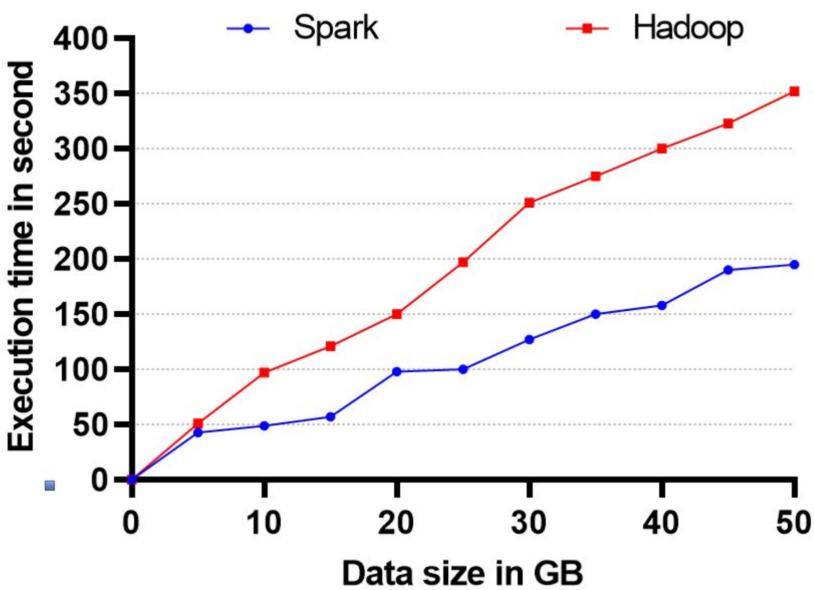

Figure 6.16: Execution time for different data size of both Spark and Hadoop systems.

6.10 Data Analysis

Table 6.3: Summary of the performance matrices of the models.

Algorithms	Accuracy	Precision	Recall	F1 score
DNN	89±0.03	86±0.04	89±0.03	87±0.05
SVM	78±0.06	79±0.07	80±0.08	79±0.06
LSTM	92±0.04	91±0.04	89±0.02	90±0.06

Table 6.3 shows the summary of the result. Three models are tested with the dataset. LSTM performed slightly better than the DNN algorithm, where the accuracy of LSTM is 92% and DNN is 89%. SVM could not perform well compared with these two algorithms, where the accuracy of SVM is only 78%. The Recall value for DNN and LSTM is the same - 89%. However, Precision and F1 score for the LSTM is good. According to the dataset, LSTM is used in the Hadoop system to visualise the location so that the first responder could make a plan according to their priority of needs.

Receiver Operating Charactistics (ROC) curve is one of the important evaluation metrics for the measure of the performance of a classification model. The performance of the classification problem model can be visualised by using an ROC curve, which is plotted with the False positive rate and the True positive rate. Figure 6.17 shows the ROC curve for the performance of the model, which clearly shows that LSTM performs better than the other two classification models for the dataset.

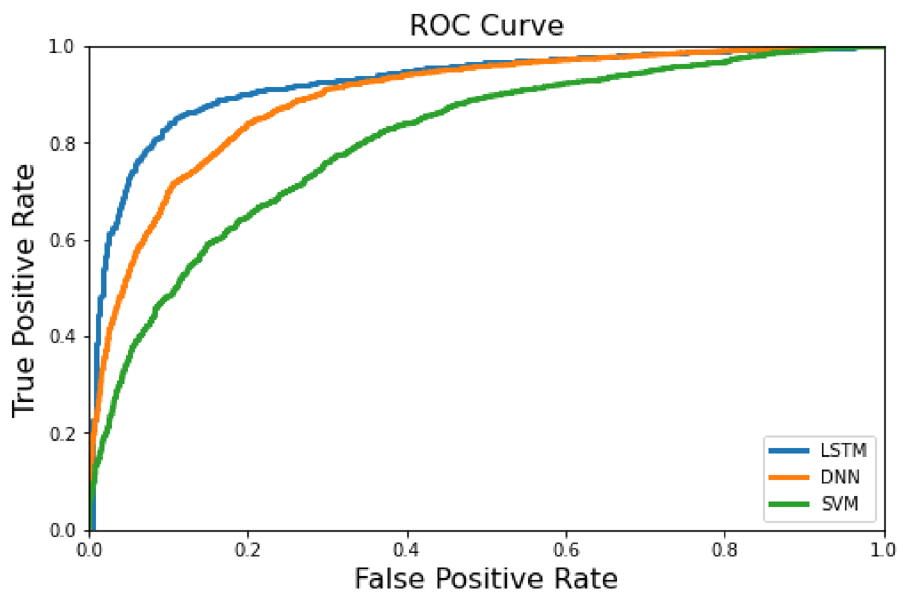

Figure 6.17: ROC curve for the models.

6.11 Summary

A massive data set generated by the natural disaster affected people through social media platforms, text messages and other communication media. These different platform data consist of different structures; as a result, the size of data during the disaster was massive and unstructured. Processing these large amounts of unstructured data is very critical and very important for the response system for disaster management. Big data technology is one of the viable technologies, which can store, process and analyse many data sets with unstructured data. In addition, the distributed cluster-based computer processing give enormous speeds of the data processing compared to the standalone system. In this work, large amount of unstructured disaster data (Synthetic and social media data) was analysed using Big Data-based technology (Hadoop and Spark distributed framework). The work calculated and compared both Map Reduce and HDFS and the next generation Spark technology. Because of the nature of data storage and processing architecture, Spark is faster than the Map Reduce, as was expected. This work also implemented a Machine Leaning model to LSTM, DNN and SVM to train and test these disaster data and compare the performance of these three ML models.

Chapter 7

Conclusion and Future Directions

7.1 Conclusion

A disaster response system (DRS) framework is needed for establishing communication, data analysis, visualisation and decision making in natural calamity events. The existing infrastructure could not guarantee the support of the seamless connection, validating data and visualisation. In this technology era, several technologies are available that need to be integrated to get a smart framework that can save many lives by a quicker response system.

The existing response system framework depends on the centralised system for the disaster management system. Because of its nature, the existing framework did not have enough capabilities to handle all the issues caused by the disaster. Moreover, the existing framework has some limitation, which needs to include the system's availability, repairability, recoverability, security, visualisation and robustness. At present DRS network fully depends on the existence of the infrastructure. This physical infrastructure can be damaged and fail to establish communication during or after the strike of the disaster. As a result, the existing network infrastructure failed to cope with the disaster situation and support other post-disaster applications requiring higher bandwidth. In addition, before and after the disaster strike, data needs verification before the analysis and process. A secure, reliable and distributed system is required to do this.

Hence, this research aimed to address the technological gap in the disaster response system and proposed designing a DRS. The research also focused on designing a robust, efficient, self-healing autonomous DRS framework that will cooperate with all disaster phases. This framework will help establish communication, enhance coverage probability, collect secure data and analyse it for prompt decisions.

To overcome the problem of the absence of the physical infrastructure, LTE technology, 3GPP introduced the D2D communication underlying the LTE network. D2D communication enables communication between devices within close proximity areas, which enhances the performance of the PSN communication system. Thus, a framework based on D2D communication has been proposed in this thesis to overcome the existing system. The focus of this research was to design a resilient communication network integrated with the emerging technologies. In the proposed framework, the network will re-establish connection automatically; and provide end users with seamless communication. Data security, storage and analysis are also taken into consideration, which are vital factors to facilitate the rescue operation more effective and efficient way. The cluster-based D2D communication establishment, data security, data storage and visualisation were set as performance matrices to measure the success of this system.

The first performance matrix is measured by analysing the performance of the clustering-based multi-hop D2D communication. A mathematical and simulation analysis is performed to measure the performance of the D2D communication based on the outage probability and energy efficiency. The simulations considered the different scales of infrastructure damaged by the disaster. The result showed a significant improvement in using D2D communication by extending the coverage, energy efficiency, and QoS in disaster communication networks. 70% individuals are expected to use a signal of at least 25dB, which is considered very excellent, and 80% of users would be able to access a signal of at minimum 5 dB. However, if the disaster's impact is significant, the outage chance will be considerable due to distance and channel conditions. When the catastrophe effect reaches 70%, QoS decreases. Only 20% of users receive QoS service in damage of 25dB, while the remaining 30% receive 15 dB. However, around 50% of consumers will be able to use the service for 5dB.

The overall network coverage probability is also calculated using the cluster-based D2D communication in a normal scenario, as well as a disaster scenario. The coverage percentage significantly increases with the increased size of the area. With the cluster-based D2D communication, overall network coverage is 20% more of any given km. The overall network coverage probability increases when using cluster-based communication. Cluster-based multi-hop D2D communication increases network coverage, reduces the consumption of energy and reduces the interference of entire nodes. For the routing and data transmission in multi-hop communication, a bio-inspired hybrid (BAO-PSO) algorithm was proposed where BAO used for clustering and PSO is used for the routing protocol. The proposed algorithm aims to increase the network lifetime, and reduce energy consumption of IoT device in disaster network that acts as D2D communication device. The simulation result showed that the network lifetime is increased 17%-23%. The proposed model achieved a higher network lifetime compared with the other state-of-the-art models, the network lifetime increasing by approximately 10%. The reason is the significant CH selection process, preventing energy consumption of the node during packet transmission, and finding the optimised route for the packet delivery.

The second performance matrix of the framework is data validation and security. Hyperledger Blockchain technology provides a distributed system to support data authenticity and validity using the validation service for secure data communication and relief operations. This system will ensure that the data received for the analysis and process is accurate, ensuring the correct result. Hyperledger Blockchain-based disaster architecture is proposed to provide user authentication, authorisation, and validation to overcome security threats like eavesdropping, the free-riding of selfish peers, and the security threats of wiretapping. This validated data used for analysis to provide the situation awareness to the people and help to give precise information and use for the early warning system. Blockchain technology can be used to validate the data block from the different D2D-activated IoT devices. The Kafka and Raft consensus algorithms are used to measure which algorithms perform well in disaster data. Both of them perform similarly. However, Kakfa is slightly better than the Raft algorithm.

The third performance matrix of the framework is data storage, analysis and visualisation of the data. In the disaster situation, data come from different sources and structures. The volume of the unstructured data size is huge. To handle the large volume of data, it has implemented the Big data technology, which is able to handle extensive unstructured data sets for the processing and visualisation. The data storage, analysis and visualisation model has been proposed. Machine Learning is used for the data analysis. The simulation model showed a heat map for the visualisation of people's needs in disaster-affected areas. Based on their needs, the rescuers will be able to make a priority of the task. The system will get accurate information on the location where people need help and what their needs are. The responders will be able to make the plan properly without any duplication.

The DRS framework needs to use integrated technologies that will be efficient, reliable and resilient to the disaster response system. The DRS will help with pre- and post-disaster situations and provide services for the DRS phases, from situation awareness to relief operations. In addition, the system also re-establishes the communication channel and provides seamless connectivity among the devices in close proximity. Using clustering-based D2D communication, devices outside of the network coverage can also connect and send data to the rescuer team.

7.2 Research Limitations

The research proposed a DRS framework which ensures robust and resilient communication capabilities in various disaster scenarios. However, there are some limitations of this research, which helps to improve the effectiveness of D2D communication in the proposed disaster response system. Some of the limitations are as below:

- The proposed framework considered the urban area where the success of the framework depends on device density. The effectiveness of D2D communication relies on the presence of other compatible devices within the range. In sparsely populated or remote areas, where there are fewer devices available, D2D may not be a viable option for communication.
- This research did not consider interference and congestion related issues. In densely populated areas during disasters when many people are trying to use D2D communication simultaneously, there may be issues with interference and congestion. This can degrade the quality of communication or even make it impossible to establish connections.
- D2D communication often operates on shared frequency bands with limited bandwidth. This can restrict the amount of data transmission simultaneously. For this reason, there will be an issue with data transmission speed especially when large volumes of data are involved.
- D2D communication, integrated with other communication technologies such as satellite communication, mesh networks, LoRa and drones could be considered and investigated for the disaster situation.
- Finally, a large scale practical testbed could give a clear picture of the dataflow for the proposed framework and ensure the effectiveness and reliability of communication in disaster response scenarios.

7.3 Future Works

Effective disaster response requires well-coordinated efforts from government agencies, non-governmental organizations, local communities, and the private sector. The faster coordination is the key success of the disaster framework. As a result, the adaptability of the emerging technology is required. The deployment time of the emerging technologies is one of the key factors for the disaster response system.

Collaborative efforts between researchers, industry, government agencies, and disaster response organizations are essential to drive progress in D2D communication for disaster response. These efforts should aim to create robust, interoperable, and efficient D2D systems that can significantly improve the effectiveness of disaster response operations. Developing standardized protocols and interfaces will enhance interoperability, enabling collaboration that is more effective. It should seamlessly integrated with other technologies, such as drones, IoT sensors, and satellite communication. In addition, minimizing communication delays is essential for real-time disaster response. Future work should focus on reducing latency in D2D communication systems, allowing for faster decision-making and response.

As technology continues to advance, the development and deployment of 6G networks are on the horizon, and they have the potential to significantly enhance disaster management and response capabilities. 6G networks are expected to be designed with enhanced resilience and reliability features, ensuring that communication remains functional during and after disasters, even when traditional infrastructure is damaged. In addition, 6G is expected to support a massive number of devices simultaneously. This capability can be valuable for connecting various D2D-activated IoT devices, sensors, and drones used in disaster response. These devices can collect and transmit data in real-time to provide a comprehensive view of the disaster-affected area. Moreover, provides ultra-high data rates, potentially reaching terabits per second. This high-speed connectivity can enable the rapid transfer of large volumes of data, such as high-definition video, sensor data, and images, which is crucial for assessing disaster situations and making informed decisions. Though, 6G networks are still in the research and development phase, it can solve the connectivity and data processing challenges faced during disasters.

Low Earth Orbit (LEO) satellites offer several advantages for disaster response framework and they are just one part of a comprehensive disaster response strategy. The integration of satellite data with other data sources and technologies, such as ground-based sensors and drones, can enhance the overall response capabilities.LEO satellites can be used for emergency communication and data transmission. They can facilitate communication in remote or disaster-stricken areas where terrestrial infrastructure may be damaged or non-existent. This is essential for coordinating relief efforts and providing critical information to affected populations. In addition, LEO satellites data can be processed using machine learning and data analytics techniques to extract actionable insights. This can assist disaster management agencies in making informed decisions. There are some of limitations and challenges which need to be addressed in future. Effective data processing, storage, and analysis systems are needed to make the data actionable for disaster management agencies. This requires robust infrastructure and skilled personnel. In addition, LEO satellites offer low-latency communication compared to geostationary satellites, there is still some latency involved due to signal travel time to and from space which needs to be addressed in future to use more efficient ways in disaster situations.

In conclusion, this thesis focuses on integrating emerging technology with the disaster response framework to enhance the performance of the system in terms of network lifetime, coverage probability, QoS, data security and visualisation of the data. This helps to reduce the time of rescue operation which can save many lives.

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