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Research Article

Enhancing Resilience in Communication Networks for Post-Disaster Response

Ratna R. Sarkar[1], Mohammad Zahidur Rahman[2]
Department of CSE, Jahangirnagar University, Savar, Bangladesh
ratnacse2013@gmail.com
rmzahid@juniv.edu

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ABSTRACT

The conventional communication system may col- lapse due to natural or other man-made disasters. This break- down might make the disaster's aftermath worse. Setting up an alternative or emergency communication system can be extremely helpful in alleviating suffering and making it easier to carry out rescue and relief operations. Concerning this situation, this work presents a resilient data transmission architecture for establishing communication in such a critical situation. This communication system provides a way to make communication between victims and rescuers in an infrastructure-less environment. The effect of mobility models is also examined by simulating the scenario using ns-3, which helps enhance the resilience of communication. For this simulation, the Random Walk 2D, Random waypoint, and Random direction 2D mobility models are considered mobility models. The parameters analyzed to assess the Quality of Service (QoS) of this communication architecture include Transmission Bit Rate, Receiving Bit Rate, Delay and Packet Loss Ratio (PLR). The study's outcome involves determining the most suitable mobility model for the presented transmission architecture, based on its performance and suitability.

Keywords: Mobility Model; QoS;Resilience;Communication

I. INTRODUCTION

When natural disasters like tsunamis, typhoons, hurricanes, and earthquakes strike, the world faces significant disaster management challenges. These natural disasters wreak havoc on specific geographic areas and threaten human lives, other living organisms and environmental degradation. Natural dis- asters and man-made disasters are the two types of disasters [1]. Natural disasters occur as a result of the physical and biological nature of environmental events. There are three types of disasters: geophysical, meteorological, and biological [2]. These natural disasters also damage or completely disrupt the traditional cellular communication system. Gathering infor- mation is one of the most important concerns in a post-disaster situation in order to expedite relief and rescue operations. After a disaster, synchronizing relief and rescue operations becomes critical. In this case, ICT (Internet communication technology), a promising technology that includes fields such as IOT (Internet of things), cloud computing, data analytics, and so on, may help with smart disaster management [3]. It also helps to save more lives and reduce the disaster's aftermath. Some daily life facilities, such as water, electricity, and food supply, are severely impacted by natural disasters, which can be fatal in some cases. Communication is critical during a disaster to keep living agents safe, alleviate victims' suffering by providing food and emergency medical assistance, locate missing family members, and carry out relief operations efficiently. In such a situation, prompt response and the need for emergency service efforts become imperative. In such a case, establishing an emergency communication system may be a viable option for mitigating the aftereffects of a disaster.

This work presents a spontaneous and resilient data trans- mission architecture utilizing low-end communication devices in a such post-disaster scenario to mitigate the aftermath of the disaster. This system establishes a way of communication in a such catastrophic situation. This communication system offers a method to establish redundant communication pathways that do not rely on preexisting infrastructure. Additionally, two re- silient protocols are proposed for the entire system to facilitate emergency communication. These protocols are designed to ensure the system's robustness and enable effective commu- nication during emergency situations. This system emphasizes compatibility and interoperability by enabling participants to connect to the system using various types of communication devices. The primary focus of this work is to leverage low-end handheld communication devices for establishing communica- tion in emergency situations, such as post-disaster scenarios. The goal is to explore the potential of these devices and their suitability in facilitating effective communication during critical times. The mobility of each node in such a network must be taken into account. In this communication system, which establishes an Adhoc network, node mobility plays a pivotal role. The network consists of mobile nodes, and their movement patterns are highly unpredictable. Nodes have the freedom to move spontaneously within the network, making their mobility patterns uncertain and dynamic. The position, speed, velocity, direction, and other factors can be used to compute a node's mobility at any given time. In a real-world scenario, it becomes difficult to identify the nodes' mobility. Identification of the mobility pattern of nodes is aided by mobility models. In order to simulate this communication scenario, considering the mobility model may be necessary to identify the nodes' mobility and that may have an impact on the network's performance. Various mobility models, including Random Walk 2D,Random Waypoint, and random direction 2D, are taken into consideration in this work to define the nodes' pattern of mobility. Ns-3 [4] is used to simulate this spontaneous communication architecture presents in this work. In this simulated environment, both the Random Walk 2D and Random Waypoint mobility models demonstrate superior performance according to the parameters under consideration, thereby ensuring effective Quality of Service (QoS).

In this paper section 2 represents the literature reviews along with the problem statements and research gap of the work. Section 3 presents the architecture of the data transmission model proposed for a post-disaster scenario. Section 4 contains the performance evaluation of this communication model along with the considered parameters for the simulation environment and finally the result and discussion. Finally, conclusion and future direction is in the section 5.

II. LITERATURE REVIEW

The author presents a routing strategy for effective data dissemination in a critical situation using the concept of MANET and DTN. The network architecture also includes relief workers who collect information and pass it on to throw boxes, which also serve as storage and send to the main control station [5]. The author examines various types of MANET routing protocols on multiple parameters such as security, energy, and so on and discusses various future research issues especially in disaster management [6]. The authors propose a method for accelerating disaster relief op- erations by utilizing people's phones. The main goal of this system is to create a channel for survivors to help speed up the relief operation by ensuring wide coverage with a small number of devices along with internet connectivity [7]. The author proposed a hybrid disaster management system that combined the concept of VANETs and VCNs and made up of smart vehicles (VaaR). This system also makes use of a cellular network as well as an Adhoc network. Within the zone, cellular networking is used, while Adhoc networking is used between relay nodes [8]. ReDiCom is proposed for resilient communication for disaster management based on layer architecture, information and network layer. The information layer enables data dissemination through the roles and identities of responder teams that are formed dynamically, and the network layer ensures vigorous communication for fastening disaster management. The concept of ICN (Information Centric Network) is followed to form the responder team [9]. The author presents a self-created communication model that aids in recovery plans in disaster management. The proposed model comprises public, social media, and intelligent applications. Intelligent applications use social media platforms such as Facebook and Twitter to disseminate emergency messages and ensure proper disaster management [10]. According to the author's proposed architecture, the police, fire service, and other services are all linked to the government authority so that they can collaborate. On the disaster-affected site, an infrastructure is set up to provide a hot spot or a wireless LAN (Adhoc Network) for data dissemination. The author also mentions some challenges with this system, such as security, ensuring data integrity, reliability, and non-repudiation [11]. The author proposes RDSP for proper disaster management in a post-disaster scenario, which employs novel routing techniques such as Dynamic ID Assignment (DIA) and the Minimum Maximum Neighbor (MMN) algorithm. When the system detects a request message, it selects the relay node with the lowest ID; when an acknowledgement message is detected, it selects the relay node with the highest ID [12]. The author of this study identifies the challenges and efficacy of this traditional disaster management cycle in the circumstances of urban flooding in Pakistan. The study's findings emphasize the importance of non-structural measures in reducing the risk of flooding in urban areas [13].

Immediately after the natural disaster, the traditional network becomes intermittent or totally broken. Establishing connectivity in such an intermittent network becomes hardly possible for victims. Delaying communication could result in more victims, more fatalities, and excruciating suffering. Concerning these issues establishing a simple and easily usable communication network for victims becomes obligatory. Establishing a network with no infrastructure and disseminating data over the network become difficult in such circumstances. This work presents a resilient data transmission architecture that takes these concerns into account. This initiative's main goal is to speed up communication so that victims may quickly use the basic communication equipment they are carrying to seek critical emergency supplies like food, shelter, and medical care. This suggested communication system is capable of establishing a line of communication between victims and rescuers in an emergency. This system is incredibly user friendly and allows for rapid communication with no setup needed.

III. ARCHITECTURE OF THE DATA TRANSMISSION MODEL

This data transmission model aims to minimize the impact of a disaster by effectively managing communication in the post disaster scenario. This communication model utilizes low end communication devices. Figure 1 illustrates the visual depiction of this communication model. This work extends the findings of our earlier work [23]. The architecture is constructed in a way that allows for the addition of more nodes and advanced data management methods, such as distributed storage, data indexing, and query optimization [26]. Natural catastrophes are most commonly associated with the destruction of traditional network infrastructure. Most communication links and network equipment fail. Natural catastrophes can potentially affect the signal strength of a wireless network. The unreliable communication infrastructure has made executing rescue efforts challenging. Bangladesh is disaster-prone, and the aftermath of a disaster causes significant suffering in the affected area, particularly in terms of communication. Due to Bangladesh's unique geographical location, the country is susceptible to a variety of natural disasters, including floods, cyclones, and earthquakes. In the aftermath of such events, traditional communication systems often become sporadic or inoperable, hampering the dissemination of critical emergency relief messages from victims to responders [24]. Furthermore, this catastrophe could have harmed the vehicle path, making it harder to access the impacted location. In this case, extending the rescue operation may cause more life losses. Following a disaster, an effective communication system is essential to carry out rescue, relief, reaction, or recovery efforts. This communication technology speeds up these vital tasks, saving lives and enhancing disaster management overall. Following a disaster, this technique improves communication resilience .

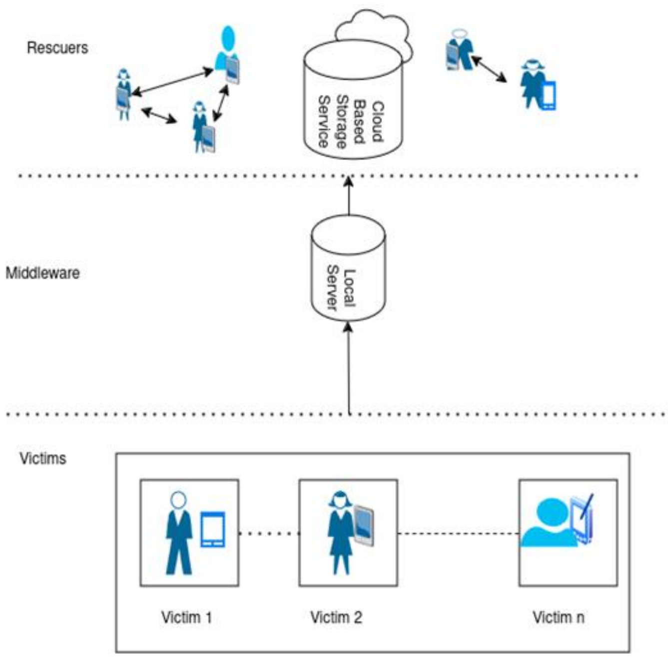

Fig. 1. Data Transmission in a post-disaster Scenario

Figure 1 displays the architecture of the proposed communication systems. Initially, catastrophe victims use the system's user interface to request immediate emergency assistance. The microcontroller device functions as the victim's local server, storing and relaying emergency aid messages. Victims can request emergency help by connecting straight to this device. It is also responsible for establishing the network zone so that victims can access the system and get life-saving services.

We propose and develop a post-disaster communication system to facilitate emergency contact between victims and rescuers. A victim can disseminate message to request the help they need once they connected to the system. This method can be very helpful in the recovery process after a disaster and saves more lives. The ESP8266 microcontroller module, which is inexpensive and low-power, is used to implement the system [25] .

This communication technology is primarily intended to provide emergency communication when traditional communication systems fail or become intermittent for transmitting data quickly following a natural disaster. It is critical to send data in such scenarios in order to receive emergency service requests from victims and expedite the rescue and relief operations, which can eventually help to save more lives and reduce the consequences of the disaster. The suggested communication system is separated into two parts: V2R and R2R. V2R is for Victim to Rescuer Communication, whereas R2R stands for Rescuer-to-Rescuer Communication. In V2R, this system takes emergency requests for services such as medical assistance, rescue assistance, and so on from victims and distributes them to the system. R2R communication allows rescuers to communicate with one another. Rescuers can communicate a variety of information, including detailed updates on the present condition of the catastrophe scenario, information on what resources are needed and what is available, updates on the condition and well-being of rescue team members, details about victims that require assistance, critical information to safeguard the safety of rescuers. Information about the status of communication networks, rescue operation techniques and plans, medical conditions and needs of victims and rescuers, and so on. This component of the communication system uses device-to-device communication to share and exchange information. Overall, several components of this system work together to mitigate the disaster's overall impact.

- Victim-to-rescuer communication is an essential component of emergency response, ensuring that people in distress may express their needs and receive prompt help. Effective communication between victims and rescuers can dramatically enhance the outcomes of rescue operations, saving lives and giving critical aid more effectively. In this kind of communication, victims and a local server build a spontaneous network that helps them distribute crucial emergency assistance. This local server is placed in the middleware of the proposed communication system. Victims use this suggested approach to initiate emergency messages for rescue, medical, or other assistance. Algorithm 1 is followed for collecting the emergency assistance messages from the victims. This algorithm focuses on forwarding emergency messages efficiently based on clients encountered. After being connected it counts the number of clients. If multiple clients are present, the system establishes a connection and forwards the emergency message to the rescuers. The client and server modes are altered as needed to ensure effective data transfer.
- Algorithm 2 is mainly used to propagate the collected emergency assistant messages from the victim to the rescuers team. So that the rescue operation might be done right away with an effective measure. Rescuers are vital in providing immediate assistance to persons in need, guaranteeing their safety and well-being, and helping recovery efforts after disasters. Rescuers search for survivors and assist them in leaving the catastrophe area. They are also well-equipped to provide medical services such as first aid and emergency medical services, which will save more lives and, eventually, reduce the overall impact of the disaster. To properly respond to calamities, rescuers must communicate with one another. The technology claims that by using a UI, rescuers may transmit critical or urgent information about victims to one another. They can use this UI to communicate via broadcast or instant messaging. This accelerates the rescue and relief operations, reducing the disaster's impact. Rescue teams employ internet-connected "smart" trucks that allow for communication between vehicles and with infrastructure. This addition considerably improves the whole communication system.

Algorithm 1 Emergency Assistance Message Collection Scheme **Notation:** Number of client N_c , Emergency Message E_m, Message M ,Server S, wifi generation w_g, Connection Establishment E_c, Client mode M_c, Intermediate server S_i.

1. IF w_g is generated then count N_c.
2. **IF** $N_c > 1$ **THEN**
3. $E_c \rightarrow True.$
4. Forward $E_m \rightarrow S$
5. S Switched $\rightarrow M_c$ 6. Forward $E_m \rightarrow S_i$

ELSE
$E_c \rightarrow False.$
END IF

Algorithm 2 Propagating Collecting Message Scheme

Notation: Emergency Message E_m, Received Message R_m, wifi generation w_g, Connection Establishment E_c, Client mode M_c, Intermediate server S_i , Web server W_s ,Rescue Team R_t.

IF $R_m = E_m$
$w_g \rightarrow True.$
S_i Switched $\rightarrow M_c$
IF S_i connected to $\rightarrow W_s$ **THEN**
$E_c \rightarrow True.$
$E_m \rightarrow W_s.$
$E_m \rightarrow R_t.$
ELSE
$E_c \rightarrow False.$
END IF

IV. PERFORMANCE EVALUATION

The results of the simulation of the presented commu- nication system in a post-disaster scenario are discussed in this section based on the various mobility models. As discussed earlier to design the simulation environment for such type of network nodes mobility must be considered. For this simulation scenario Random walk-2D, Random waypoint and Random direction-2D mobility models are considered. This simulation analyzes the effect of mobility models based on the density or number of nodes. This simulation examines how mobility models based on node density or quantity affect the system. These experiments aid in the identification of precise mobility models capable of delivering efficient performance and upholding Quality of Service (QoS) standards for the entire communication system in a post-disaster scenario. The discussed communication system is simulated in ns-3 [4] to evaluate the performance of this entire system.

Different simulation scenarios of 25, 50, 75, and 100 nodes, respectively, are constructed for this experiment. As previously stated, the three distinct mobility models are taken into consideration for this scenario. The speed of the node was 20 m/s. The simulation took 200 seconds in total.

A. Mobility Models

Mobility of nodes presents in Adhoc network. Adhoc formations occur in areas with a high contact density and several mobile nodes. Adhoc networks are utilized in situations where a temporary network is needed, and they function in a decentralized manner without the need for a pre-existing infrastructure. These networks can be formed spontaneously, without relying on a pre-established architecture, allowing devices to communicate directly with each other. It uses human mobility to make forwarding decisions, and multi- hop data forwarding is established. End-to-end connectivity is not required for effective data forwarding. Different mobility models may be used to define the mobility patterns of the network's nodes. Mobility models offer movement patterns to identify how mobile nodes actually move in the real world. Additionally, mobility models forecast the performance of the routing protocols and help to improve overall performance [14]. In order to achieve high stability and reliability of the network, node mobility must be taken into consideration. RandomWalk2D, Random Waypoint, and Random Direction 2D Mobility Models are used to identify patterns in this simulation.

- **RandomWalk2D Mobility Model:** The Random Walk 2D Mobility Model explains how nodes move on a 2D plane by picking a random speed and direction, then moving for a predetermined amount of time or distance before picking a new random direction [15] [16].
- **Random Waypoint Mobility Model :** In the Random Waypoint Mobility Model, nodes travel at a randomly chosen speed to a predetermined location within a simulated area. It is frequently employed in mobile network simulations because, after arriving at its destination, the node pauses for a predetermined amount of time before

continuing [17][18][19][20].

- **Random Direction 2D Mobility Model :** Nodes in the Random Direction 2D Mobility Model choose a random speed and direction, move to the simulation area's edge, and then either pause or choose a different course. By guaranteeing mobility throughout the whole region, this paradigm avoids node clustering [4] [21] [22].

B. Analyzed parameters

The following parameters are considered when investigating performance.

- Transmission Bit Rate: The rate at which the number of bits is transmitted per second.
- Received Bit Rate: The rate at which the number of bits is received per second.
- Delay: Delay is the term used to describe the average time it takes for a data packet to reach its destination.
- Packet Loss Ratio: The packet loss ratio is a term used to describe the percentage of data packets that are either lost or fail to reach their intended destination in a network.

C. Result and Discussion

This simulation environment is designed in ns-3. The operation of the entire communication system is represented by the algorithms 1 and 2. The overall effect of node mobility on QoS for this communication system is examined based on two different situations. The environment in the simulation scenario is designed to accommodate a variety of node configurations, including 25, 50, 75, and 100 nodes.

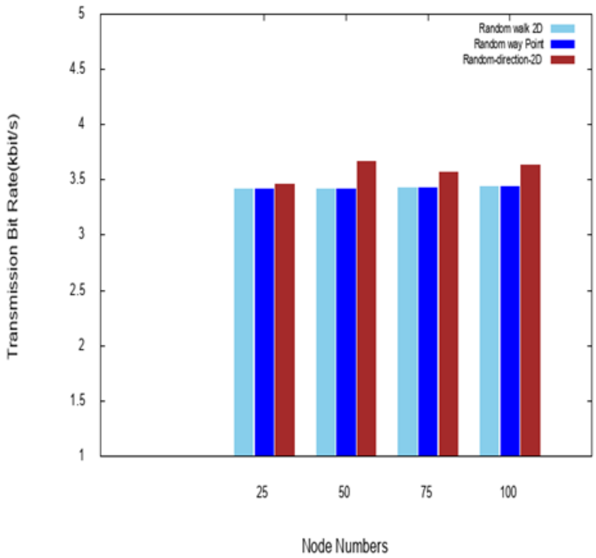

Fig. 2. Comparison of Transmission BitRate

Figure 2 depicts a comparison of three different mobility models based on transmission bit rate, which is measured in kbit/s. The Random Direction 2D mobility model outper- formed the other two mobility models in terms of transmission bit rate. The performance of the Random Walk 2D and Random waypoint mobility models in this experiment is nearly indis- tinguishable. Higher transmission bit rates typically result in faster data transfer and an improved user experience, which improves QoS. Based on the results of the experiment, it can be concluded that the Random Direction 2D mobility model is a viable choice to be considered for this scenario.

Figure 3 depicts a comparison of three different mobility models based on the receiving bit rate, which is also measured in kbit/s. In the case of 50 nodes, the Random Direction 2D mobility model exhibits the highest receiving rate compared to the other mobility models. However, in the case of 100 nodes, it demonstrates a lower receiving rate compared to the other mobility models. The Random Walk 2D and Random Way point mobility models consistently deliver consistent performance across the entire simulation environment.

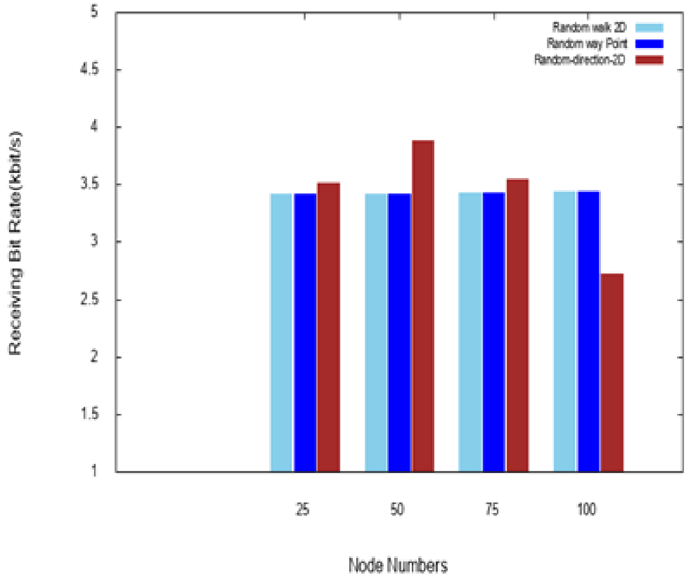

Fig. 3. Comparison of Receiving BitRate

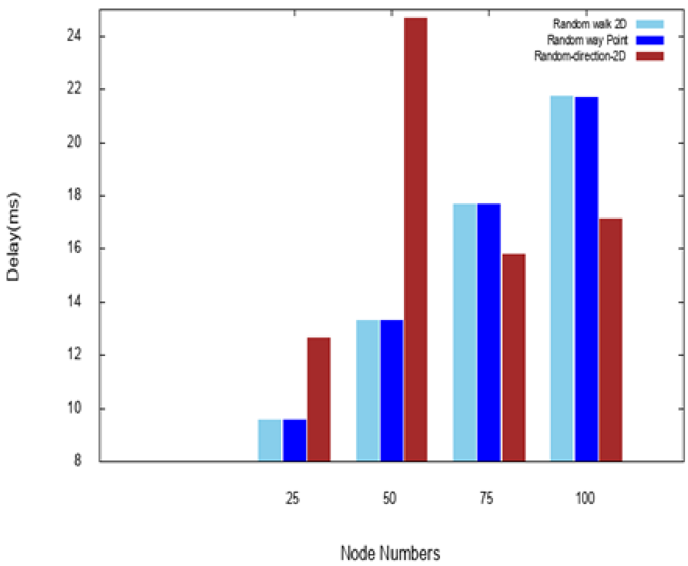

Fig. 4. Comparison of Delay

Figure 4 provides a visual representation comparing the performance on delay among three different mobility models. Except when 25 and 50 nodes are considered, the experimen- tal results show that the Random Direction-2D has a lower delay than others. Achieving a high level of overall network performance is heavily reliant on minimizing delay, as lower delay is critical to ensuring efficient network performance. Random walk 2D and Random Waypoint mobility models exhibit almost similar levels of performance throughout the scenario. The experiments concluded that as the number of nodes increases, the delay also increases. This implies that in larger networks, the delay becomes higher compared to smaller networks.

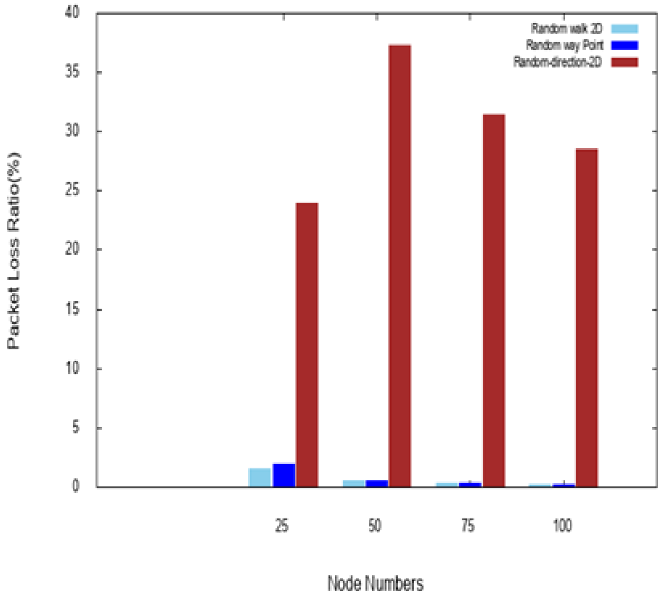

Fig. 5. Comparison of Packet Loss Ratio

Figure 5 illustrates the comparison of the Packet Loss Ratio, which is measured in percentage %. Based on the experimental results, it was found that the Random Walk 2D and Random Waypoint mobility models outperformed the random direction 2D mobility model. Achieving a lower packet loss ratio is beneficial for improving the efficiency of a network's performance and enhancing the QoS of the network. Due to its higher packet loss ratio, the random direction 2D model is not suitable for the experimental scenario. In evaluating packet loss ratio, employing mobility models such as Random Walk 2D or Random Waypoint can lead to more impactful outcomes.

The experimental results mentioned above provide a comprehensive understanding about the performance of these three distinct mobility models, provide valuable guidance in selecting the most efficient mobility models for this particular network type.

V. CONCLUSION

In the kinds of communication models presented in this work, node mobility is crucial. In this resilient data transmission model, the impact of several mobility models in a post-disaster scenario is examined using transmission Bit Rate, Receiving Bit Rate, delay and packet loss ratio as assessment criteria. These assessment criteria also assist in determining the QoS of the discussed communication model for the post disaster scenario. A network's performance must be maximized by achieving high transmission Bit Rate, Receiving Bit Rate while reducing delay and packet loss ratio. This implies that data should be efficiently and promptly transmitted through the network. In this simulation environment, three distinct mobility models are being taken into consideration: Random walk-2D, Random waypoint, and Random direction-2D. This means that the simulation considers three different ways in which nodes can move around the network, each with its own unique characteristics and patterns. According to this analysis, the QoS (Quality of Service) of the network is significantly influenced by the specific mobility model used. In this simulation scenario, it was observed that different mobility models achieve varying levels of performance across the different parameters considered. Each mobility model has its strengths and weaknesses in terms of the specific aspects being analyzed. When considering the transmission bit rate, the Random Direction 2D mobility model demonstrates efficient performance. It performs well in terms of the data transmission rate, indicating its effectiveness in maintaining a high bit rate during mobility. Both the Random Walk 2D and Random waypoint mobility models demonstrate reliability and stability in terms of receiving data, as well as maintaining accept- able levels of delay and packet loss ratio. Therefore, when considering these specific evaluation metrics, both mobility models can be considered suitable option. The preceding discourse and evaluation can be advantageous for numerous researchers in comprehending the impact of diverse mobility models in ensuring the performance of the network. This section will also assist to enhance the understanding of utilizing mobility models in varying situations i,e post-disaster scenarios. The potential area of expansion for this work is to enhance the performance by reducing delay by constructing an efficient mobility model.

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