GWRS Routing for Disaster Recovery Scenario

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***Abstract*—Natural disaster can strike at any time and in any place. Once it has occurred, it can ruin large regions, cause damage to houses and buildings, and destroy physical communication infrastructure. Therefore, a network backup is required in the disaster recovery area because victims will want to contact their important person to update the current situation as soon as possible. A mobile ad hoc network (MANET) is a collection of mobile devices that dynamically communicate with each other without any physical infrastructure. This feature offers a solution for communication problems during disaster recovery and keeping communication in disaster recovery areas alive. In this paper, an efficient routing scheme (GWRS) is proposed to eliminate the congestion that occurs when people in a disaster recovery area want to connect to a network. This new scheme provides a flexible and feasible approach in determining the best route. The routing scheme will simplify the selection of routes and prevent nodes from broadcasting packets to the entire network. In addition, this scheme eradicates any redundant nodes in each level of the routing table. These schemes have been simulated in a realistic environment of disaster recovery area. Ad-Hoc On-Demand Distance Vector (AODV) and Destination Sequenced Distance Vector (DSDV) routing schemes were also selected to be simulated in the same environment because these schemes show the best performance for reactive and proactive categories in emergency scenarios . Then, the performance of the proposed scheme was compared to these two schemes and evaluated through computer simulations using OMNET++ simulation tools. The results have shown that our proposed method has better results.**

1. Introduction

A natural disaster is a sudden and exceptional event that can strike anywhere in the world; examples of natural disasters include floods, hurricanes, tornado, earthquakes and tsunamis. Disasters can destroy telecommunications infrastructure. Cellular communication may not be possible after a disaster, which can cut people off from information and communication. Most people now connect to the Internet using smart devices and make calls and send text messages through social network applications. When infrastructure fails after a disaster, traditional phone calls might not get through. Restoring cellular networks after physical damage is expensive and can take a long time. A MANET is one solution in this situation. A MANET is capable of being a self-organized, self-recovery network; it is a decentralized, tariff-free operation, with easy-to-use equipment at a good cost. A MANET is suitable for unexpected conditions such as disaster response and recovery, when it is difficult or impossible to immediately build new fixed infrastructure. A MANET is apparently a good fit for search operations, as a rescue team can quickly take action in response to a victims call for help. A MANET is also suitable for recovering networks after a disaster in indoor or outdoor environments because it can be established without any infrastructure. In disaster recovery situations, victims regularly make contact with family and friends to update them about their situations. The density of nodes in a network will overwhelms the network with heavy traffic. Cell towers that are not damaged are typically overburdened and unable to handle the flow of communication. Hence, an efficient routing scheme is important, to reduce congestion. This paper examines many routing schemes in a MANET, focusing on a case study of emergency and disaster recovery scenarios. The network topography in disaster areas always changes because people move around using mobile devices, as is the definition of node mobility. Mobility features consist of node speed, direction and pauses of nodes. After a disaster, there are common obstacles and nodes change direction depending on the obstacles. Consequently, a device may disconnect from a network. As node battery life is also limited, victims are not usually connected to a network. Nodes will not appear in the routing list as they are not connected to a network. This scenario can help reduce network congestion. However, a problem occurs when other nodes do not have any single neighbor to act as a bridge to the destination node. The main contribution of this paper is its proposed routing selection scheme, and its use realistic disaster recovery environment, used to compare the performance of a proposed scheme with selected previous routing schemes. This paper is organized as follows. Section 2 presents a comprehensive background of MANET routing schemes. The formulation algorithm and problem description of the proposed routing selection schemes were elaborated in Section 3. Section 4 analyzed the performance of proposed and selected routing schemes. Next, the conclusions are presented in Section 5.

2. Background and Related Work

Routing plays an important role in choosing the best path for a packet to travel. The complexity of the routing table makes the process of routing selection difficult. Other methods, which use less hop nodes as the shortest path, cause bottlenecks, thereby decreasing network performance. Besides, mobility has a significant effect on routing performance. The performance of the routing scheme depends on the total duration of the connection between any two nodes. However, the connection may be lost during data transmission because of mobility. Therefore, in self-organized networks, metrics need to be considered to determine the best path, such as the most reliable and stable path, instead of the path with less hop nodes. An efficient routing selection scheme will simplify the complexity of route selection to reduce delay in MANET performance.

MANET routing selection schemes are generally grouped into proactive, reactive and hybrid. The Optimized Link-State Routing Protocol (OLSR) and Destination Sequenced Distance Vector (DSDV) is an example of well-known proactive routing protocols. This algorithm is stable and easy to apply in the static network topology because the route can be fast when calculated locally. However, in an environment of heavy mobility, a routing table may increase packet delay.

Difference to Ad-Hoc On-Demand Distance Vector (AODV), this reactive routing scheme practices hop count to find the shortest path from sender to receiver. It is a trusted metric, simple and effective. Even though routing overhead can be reduced, the main problem is a packet delay, because nodes wait for a route connection to be established from sender to receiver. Establishment routes are only established upon request. This type of routing may be a right solution for a disaster scenario on the condition that there are no obstacles in the path [1]. Without information updated, communication may lost if nodes suddenly disappear from a network. More problem can occur when network nodes are in high-speed mobile [2].

On the other hand, the hybrid protocol uses a combination of advantages from proactive and reactive algorithms. The algorithm was enhanced to give better solution and minimize the weaknesses of reactive and proactive approaches using zone and cluster routing. For that reason, hybrid approaches can perform in a very wide range; otherwise, reactive or table-driven approaches are more suitable. There are other categories of routing protocols, such as location awareness, multipath, hierarchical, multi-cast, geographical multi-cast, and power-aware. Until 2009, researchers still applied ant techniques to their studies. Wang et al. highlighted routing method HOPNET [3], based on ZRP and DSR, with the combination of Ant Colony Optimization. This technique is a picture of ant hopping at each zone. Forward ants will collect information about destination nodes base on routing table information received from local nodes. Then, ants move from one zone to another via border nodes. Reddy and Raghavan [4] performed an improvement of network overheads by proposing multi-path routing protocol, with one path as a primary route. Regular primary paths are set as the shortest path. Each node allows the reception of multiple copies of the RREQ packet, but does not allow the source node to reply, to reduce the network overhead.

Conversely, AQOR [5] use limited flooding in route discovery. RREQ includes bandwidth and end-to-end delay constraints. This technique will rebroadcast messages to the next hop if satisfied with the constraints. SLR [6] introduces the bypass routing technique to improve route discovery process, caused by broken links. It initiates local recovery procedures, bypassing the broken link. Yu et al. had the same interest in replacing the broken routes. They proposed a technique to intelligently change the damaged routes. Intermediate nodes that overhear the transmission between the source and destination node will potentially be a candidate for replacing the failed node. DDR [7] is used today as a backup, because of high cost. The connection is established only when needed, and turned off automatically when no information is sent. Moreover, many researchers have utilized AODV routing protocols, such as GRP [8]. Source nodes broadcast destination query packets until they arrive to the destination node. However, some schemes used source routing, which does not rely on the routing table [9]. Similarly, DBR2P [10] uses no routing table. The source node receives complete information on routes from the destination node. Multiple backup routes also settle up by destination nodes, aided by intermediate nodes, which are used in the event of a link failure. After almost 10 years, routing failure connection is still a concern in many studies. SCaTR [11] proposed a solution if route to destination is not available, and proxy request forwarded. Each node will advertise itself as the proxy destination when proxy request messages are closer to the destination node. Advertisements are used to suggest a route to the destination, and solicitation is used to ask for information to the destination [12]. For a network with asymmetric links, A4LP [13], [10] introduced a limited packet forwarding technique. The receiver must qualify a pre-set fitness value by the sender before rebroadcasting a packet.

3. Formulation Algorithm and Problem Description

There is a relatively small body of literature concerned with MANET routing protocols in the emergency and rescue scenario. The analysis of routing scheme shows among the reactive routing scheme, AODV has shown the best performance of routing metrics in the category. Meanwhile, DSDV has been suggested as performing well between proactive routing schemes, in reference to emergency scenarios. DSDV is also mentioned as performing better in

TABLE 1. OPTIMIZATION OF MANET ROUTING SCHEMES

Routing Scheme	Shortest Path	Broadcast	Multiple Routes	Route Repository	Overhead	Emergency	Node Mobility
ABR	Strongest Associativity	✓	–	✓	Medium	×	✓
TORA	✓	✓	✓	✓	High	×	×
SSBR	Signal Strength	✓	–	✓	Medium	×	✓
FORP	–	✓	–	✓	Medium	×	✓
AODV	✓	✓	–	✓	High	×	×
ROAM	✓	–	✓	✓	Low	×	×
DSR	✓	✓	✓	–	High	×	✓
ARA	✓	✓	✓	✓	Medium	×	✓
AQOR	Link Bandwidth	✓	–	✓	Medium	×	✓
DBR2P	✓	–	–	–	–	×	✓
RPR	✓	✓	–	✓	High	×	×
GRP	✓	✓	✓	–	High	×	✓
SLR	✓	–	✓	–	High	×	✓
Beraldi	–	✓	✓	–	High	×	✓
LDR	✓	–	–	✓	High	×	✓
SMORT	–	✓	–	–	–	×	✓
Yu	✓	–	–	–	–	×	✓
LBAQ	–	✓	✓	–	High	×	✓
LSR	–	–	✓	✓	High	×	✓
SWORP	–	–	–	✓	High	×	✓
OD-PFS	–	–	–	✓	Medium	×	✓
DAR	Weighted	–	✓	✓	Medium	×	×
QMRB	–	–	–	✓	High	×	✓
SCaTR	–	–	✓	✓	High	×	✓
DSDV	✓	✓	–	✓	Low	×	×
WRP	✓	–	–	✓	Low	×	×
CGSR	✓	–	–	✓	Low	×	✓
GSR	✓	✓	–	✓	Low	×	✓
STAR	✓	–	–	✓	Low	×	✓
R-DSDV	✓	–	–	✓	Low	×	×
OLSR	✓	–	–	✓	High	×	×
HOLSR	✓	–	–	✓	High	×	✓
QOLSR	Periodic	–	–	✓	High	×	✓
ZHLS	✓	✓	✓	✓	Medium	×	✓
DST	Tree neighbour	–	✓	✓	Low	×	×
RDMAR	✓	✓	–	✓	High	×	✓
DDR	Stable Routing	–	✓	✓	Low	×	×
LANMAR	✓	–	–	✓	Medium	×	✓
FSR	Scope Range	–	–	✓	Low	×	✓
SLURP	InterZ/IntraZ	–	✓	–	High	×	×
ZRP	✓	–	–	–	–	×	✓
ANSI	✓	✓	✓	✓	Medium	×	✓
FZRP	✓	–	–	✓	Medium	×	✓
A4LP	Power Consumed	✓	✓	✓	Medium	×	✓
HOPNET	✓	–	–	✓	High	×	✓
AOMDV	–	✓	✓	✓	–	×	✓
BATMAN	✓	✓	–	–	Medium	×	×
BCHP	–	✓	–	✓	–	✓	✓
DYMO	✓	–	✓	✓	High	×	✓

terms of packet delivery performance. The simulation performance between our proposed routing selection scheme and DSDV and AODV is compared, using a case study of the disaster recovery. We chose AODV and DSDV because these protocols show the best performance in their category. Reina et al. [14] believed that routing protocol in ad hoc networks will have a significant effect on the performance of a MANET, and that it is suitable for application in disaster scenarios as no infrastructure is needed.

As we compared our schemes to AODV and DSDV, we used the same realistic environment [1], to evaluate our schemes as shown in the Figures 1 and 2. In this study we chose Lojas city to simulate our proposed scheme, as well as AODV and DSDV routing protocols, using the same parameter environment. By considering AODV in a disaster recovery scenario, the scheme uses a hop count to find the shortest path from sender to receiver. The route from sender to receiver is only established when it is needed. A sender node will broadcast RREQ for connection, and an intermediate node will forward the message until it arrives at the destination node. The broadcast technique will bring a broadcast storm, as the network is inefficiently flooded and sends messages to all nodes within range to find the best route. Broadcast messages to discover the path to the destination will grow the network overhead. Each node that receives the message will record temporary routes back, and routes with less hop numbers will be chosen.

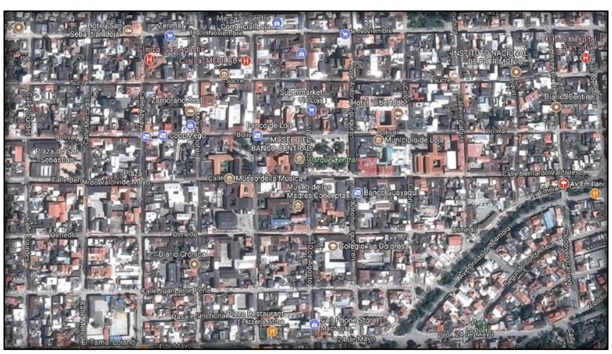

Figure 1. Loja city on Google maps

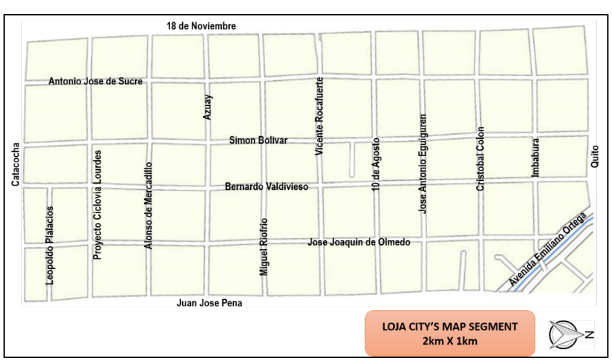

Figure 2. Loja city map segment [1]

In disaster recovery, a node represents a person in the area. Each node is free to move randomly. Hence, maintaining all routing information periodically for each node in the mobile environment is not efficient because it will drive the network overhead, because of high channel usage. Additionally, to extend battery life, sometimes a node in the network will join and leave the network. Therefore, continually refreshing the routing information in a high mobility environment and changeable network topology is not effective.

Developing a routing scheme in a MANET for the disaster recovery area has several issues: (i) network congestion, (ii) node mobility, (iii) network overhead and (iv) energy resources. However, in this study we are not focusing on the energy problem, so the energy issue assumed has been solved.

Before communication commences, as in Algorithm 1, each gateway broadcasts its coordinates and current moving speed to its neighbors within a maximum transmission range. Each gateway has an assigned, pre-set, threshold. When a gateway is almost full, the gateway node sends full notifications to nodes at level one. The objective of this technique is to reduce network congestion. As can be seen from Algorithm 1, neighbors of the gateway are stored in the routing table at level one. Nodes in level one determines their neighbors within range and are stored at level two. This process continues until all nodes are stored in the level.

Algorithm 1 Gateway(G) determines neighbor (T1)

Require: $G \geq 1$
  $T1 \leftarrow Level1$
  if $T1 < 1$ **then**
    Check redundant [] //Function redundant
  end if

Algorithm 2 determines neighbor nodes in the upper level. The algorithm also identifies node redundancy to ensure nodes are not redundant at different levels.

Algorithm 2 Each node determines their neighbor

  $T2 \leftarrow Level2$
  if $T2 < 1$ **then**
    Check redundant [] //Function redundant
  end if
  while find one S neighbors in upper level **do**
    Send a packet
    if $U = 0$ **then**
      find one S neighbors in S level //No S neighbor
      Upper level
      $N \leftarrow S$ neighbors
      Send a packet
    else
      N is waiting
    end if
  end while

According to Algorithm 3, when a node wants to send a packet out of the local network, the source node generates a route request to the gateway. The first procedure is to check the level of the source node. Looking for the next hop considers the neighbor of the source node that is located at an upper level and is in source node coverage range.

Algorithm 3 Determine level of the source node S

Require: $S \leftarrow$ source nodes
Require: $U \leftarrow$ next hope // Upper level
  while $U \neq 0$ **do**
    Send a packet // Send to one neighbor only
    if $Tn + 1 \leftarrow$ same nodes **then**
      Remove the node
    end if
  end while

If there is no neighbor node in the upper level in source node coverage range, the route request will be passed to another node in the network coverage range on the same level to find neighbors in the upper level. This method will probably increase packet delay. However, it prevents packet loss. In disaster recovery communication, information is very important. The methodology process involves gateways on the very first level of our routing scheme to send the packet out of the network, followed by the next level, which consists of gateway neighbors. The process continues until the last level of nodes.

4. Simulation and Analysis

This simulation used the same model of disaster area as in [1]. The area refers to the map of the city of Loja in southern Ecuador. In this scene for disaster recovery, 1,000 2,000m of area in the city of Loja has been simulated. We defined node movement (people with mobile devices) for our network simulation according to the random waypoint mobility model, as this is most akin to human movement. According to the behavior of this model, before nodes changing direction or speed, it will include pause times. Therefore, we set nodes speed between 0 second for static nodes and 2 seconds for pedestrians.

The placement of the node in the network is set as random because people in that area will randomly connect to and disconnect from the network. Similar to the parameter used by Quispe, we also set the number of connections as 20 and 40. The number of nodes in this simulation refers to the density of people in that area, which is 50, 97, 100, 120, 160 and 200 nodes. The difference in these density numbers can determine the behavior of routing schemes. To obtain the best scheme, we simulated AODV [15], DSDV [16] and our proposed routing selection scheme using OMNET++ simulation tools to verify our work. Model verification is important for checking the reliability of the simulation result and for evaluating the scheme. The simulation represents the results as in a real scenario. The propagation measurements were repeated three times to determine the repeatability of the results, to ensure correctness of the measurement.

In this simulation, performance analysis was carried out by an increment of the number of nodes in the simulation area and the increased number of connection nodes. Three schemes were considered for comparison: AODV, DSDV and the proposed scheme. The performance metrics, end-to-end delay, packet loss ratio, packet delivery ratio and packet throughput, were presented and analyzed.

End-to-end delay is the time that packets take to travel from the source to the destination. This include the delay caused by route discovery, buffer queuing because of congestion and packet retransmission. Figure 3 presents the results of 50 - 200 nodes density in the Loja City area, with randomly make 20 connections. From the bar chart, it can be seen that the proposed scheme slowly increased the end-to-end delay as the number of nodes increased. However, the proposed scheme had a smaller delay than AODV and DSDV.

TABLE 2. PARAMETER USED IN THE SIMULATION

Parameter	Value
Simulation area (mxm)	1000x2000
Simulation time (s)	900
Mobility model	Random way point
Mobile node placement	Random
Pause time (s)	$0 - 2$
Transmission range (m)	250
Number of nodes	$50, 97, 100, 120, 160, 200$
Number of connections	$20, 40$
Network schemes	AODV,DSDV and Proposed GWRS
Transport layer protocol	Transmission control protocol (TCP)
Nodes speed (mps)	Uniform $(0 - 2)$

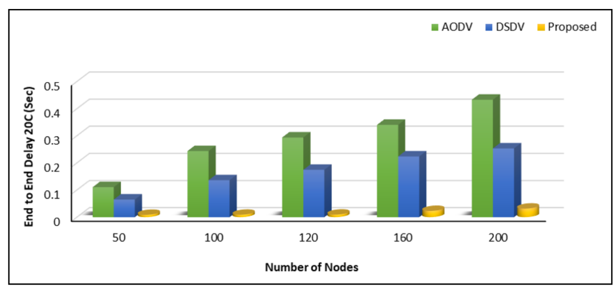

Figure 3. End-to-end delay for 20 connections

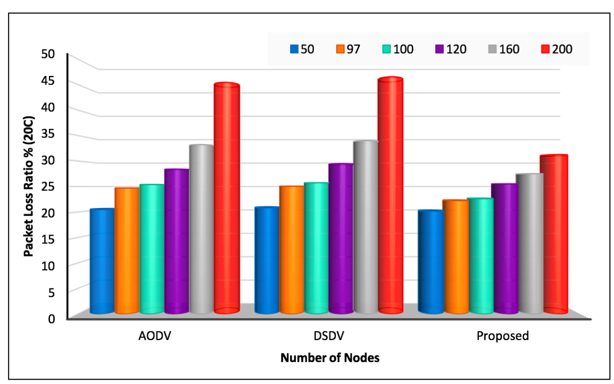

Figure 4. Packet loss ratio for 20 connections

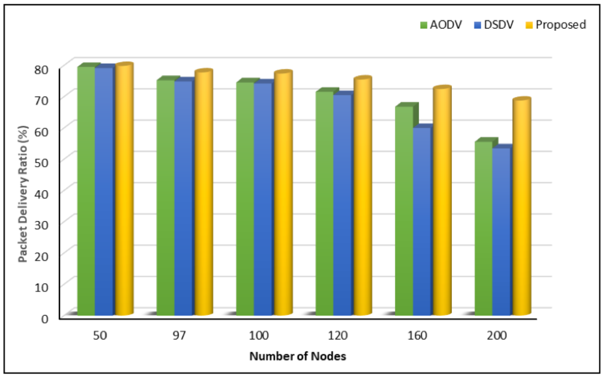

Figure 5. Packet delivery ratio for 20 connections

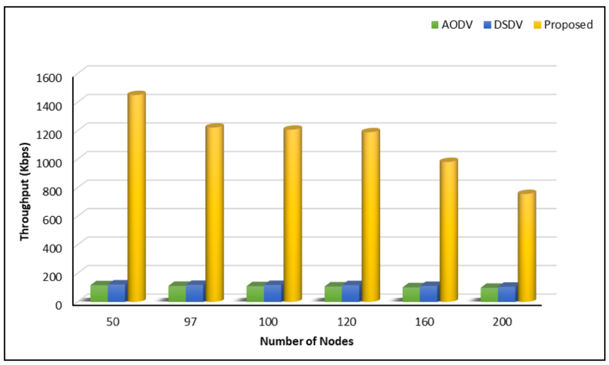

Figure 6. Packet throughput

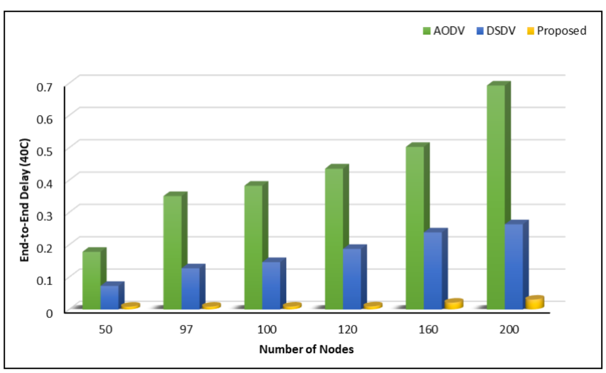

Figure 7. End-to-end delay for 40 connections

In disaster recovery, node mobility in an actual situation represents victims with mobile devices. Topology changes rapidly because of node mobility. As shown in Figure 4, from the analysis when nodes are static, the results obtained show the packet loss is slightly high. This bar chart is revealing in several ways. First, it is apparent that, at a node density of 50, packet loss ratio between the three schemes was similar. Second, as nodes increased, the form of the charts of AODV and DSDV was similar. Even though these three protocols were cumulative, our proposed scheme

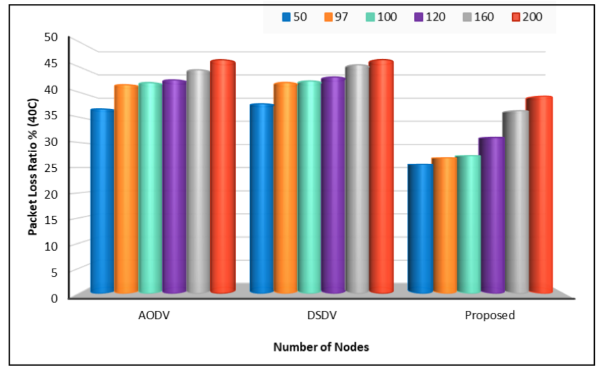

Figure 8. Packet loss ratio

showed a lower ratio of packet loss. At a density of 200 nodes, the proposed scheme increased to 31 percent, while AODV and DSDV increased to 45 and 46 percent, respectively.

Packet delivery is the ratio of successfully delivered packets to the destination nodes. The graph in Figure 5 shows that when there were only 50 nodes in the disaster area, 80 percent of the packets arrived at the destination nodes. When there were 97 nodes, there was only a 3 percent gap between the packet loss ratios of DSDV and proposed scheme. The gap gradually increased as the number of nodes increased. Packet delivery fell slowly for the DSDV scheme, making this scheme the poorest compared to the two other schemes. Our effort was to minimize packet loss because communication is in high demand and very important during disaster recovery. Another important finding was that our proposed scheme showed a significant result that provided better basic Internet access to the population of users in the recovery area. As can be seen from the graph below (Figure 6), the proposed scheme maintained high throughput compared to AODV and DSDV schemes, which had steadily low throughputs from beginning. This was probably because nodes were moving randomly. Our proposed scheme improved the problem of node mobility. Further simulation with 40 connections is shown in Figure 7. The proposed scheme demonstrated a lower increase of delay than DSDV. However, DSDV schemes had better results than AODV. AODV showed the highest packet delay when the number of nodes was 50. The figure rose higher when the number of nodes reach 200.

Figure 8 presents the results for 40 connections when the number of nodes was 50. The lowest packet loss ratios were 36 percent for AODV, 37 percent for DSDV and 25 percent for the proposed scheme. When the number of nodes was multiplied by two, the loss ratios of the AODV and DSDV schemes were similar, while the loss ratio of the proposed scheme was 27 percent. As the number increased to double, the loss ratio of the proposed scheme slowly increased to 39 percent and remained the lowest packet loss ratio.

5. Conclusion

This paper examined a list of MANET routing schemes. Despite the fact that there has been a great deal of research on MANET routing, there is still room for improvement, especially in disaster recovery scenarios. As seen in our analysis, only a few routing schemes have been concerned with disaster environments. This paper proposed an efficient routing selection scheme to manage network congestion in disaster recovery areas. The paper considered a realistic disaster recovery scenario and compared the performance of our proposed scheme with AODV and DSDV routing schemes. The performance of these three routing schemes was evaluated using the computer simulation tool OMNET++. The results of the simulations showed that the proposed scheme performed better than AODV and DSDV routing protocols in selected performance metrics. Although this study focused on disaster recovery, the proposed scheme may work well in other scenarios.

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