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Efficient Route Discovery and Link Failure Detection Mechanisms for Source Routing Protocol in Mobile Ad-Hoc Networks

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ABSTRACT The rapid advances in the wireless communication industry have paved the way for the enhancement of wireless mobile ad-hoc networks (MANETs) to support various domains including civilian environments, emergency operations, and military affairs. Source routing in MANETs is subject to some issues such as changes in the network topology, which lead to frequent link breakages that may increase the requests of route discoveries. Thus, this paper aims to enhance on-demand source routing protocols by proposing two mechanisms, a zone-based route discovery mechanism (ZRDM) and a link failure prediction mechanism (LFPM). ZRDM aims to control the flooding of route requests, and LFPM aims to avoid route breakages caused by node mobility. The performance of the proposed mechanisms was evaluated using network simulator 3 in terms of normalized routing load, average end-to-end delay, and packet delivery ratio. The experimental results showed that the proposed mechanisms outperform well-known mechanisms such as the dynamic source routing (DSR) protocol, reliable DSR, and zone-based DSR and segment-based DSR.

INDEX TERMS DSR, MANET, RREQ, routing overhead, source routing protocol.

I. INTRODUCTION

The mobile ad-hoc network (MANET) is dynamically formed by wireless mobile nodes that arbitrarily move without the administration of a base station or any central point. MANET is considered as a multi-hop network; within a multi-hop network, the source node can communicate with its destination through intermediate nodes because the destination is out of the communication range of the source node [1]–[3]. MANET is considered a promising technology that offers temporary connections without any pre-existing infrastructure, which is needed during abnormal situations or temporary events such as in emergencies, catastrophic recovery areas, and battlefields [4]. However, one of the main challenges in MANET is that the link breakages that occur disrupt the established connections [5], [6].

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Many protocols for MANET recommend the construction of routes reactively by flooding the network with route request (RREQ) packets [7], [8]. As a result, when establishing connections to the desired destination, the flooding procedure causes high control overhead, which can degrade the performance of MANET [9]–[13]. Moreover, flooding operations should be selectively controlled to improve the network efficiency by limiting the number of mobile nodes broadcasting RREQs [14]–[16]. Node mobility can cause rapid topology changes in the network; these accordingly lead to frequent link breakages that produce additional overhead and hence disruptions in the established connections [17]–[21]. The disruption events significantly affect network performance, which leads to increased delay and control overhead as well as reduced packet delivery ratio. Such issues increase the demand for an effective link failure prediction strategy. In general, routing protocols used in MANET must automatically adapt to topology changes to maintain the routes between the data source and its corresponding destination. Based on the routing process, routing protocols developed for MANET are categorized into three main categories. (i) Proactive routing (table-driven) protocols [22]–[25]; the main feature of this type of protocols is that each node should periodically exchange routing information with other nodes to keep its routing table up-to-date, regardless of whether the routes are needed [17], [26]. (ii) Reactive routing (on-demand) protocols [27]–[30]; here, a route to a destination is only searched when it is required by a source [7], [17]. (iii) Hybrid routing protocols [31]–[33]; these routing protocols share the properties and advantages of both reactive and proactive protocols. The proactive and hybrid routing protocols do not offer satisfactory performance in terms of control overhead and memory consumption reduction in a dynamic environment with frequent topology changes owing to their slow detection of and reaction to route breakages as well as the unnecessary exchange of periodic updates [34]. On-demand routing protocols were developed to save bandwidth by minimizing the use of control messages throughout the network [35]. A route to a destination is only searched when it is required by the higher protocol layers. Reactive routing protocols can be categorized into two classes: hop-by-hop routing and source-based routing [36]. Hop-by-hop routing protocols such as on-demand distance vector (AODV) carry only the destination and next-hop addresses in their data packets header, whereas source-based routing protocols such as dynamic source routing (DSR) carry the entire path to the destination [36]. DSR is one of the more generally accepted on-demand routing protocols; itis a well-known dominant source routing protocol that imposes itself as a prerogative routing protocol with such aspects [37]–[39]. DSR uses two main mechanisms: route discovery and route maintenance [40]; both these mechanisms operate when there is a demand for a route. However, new routes are mainly discovered by flooding the network with RREQ packets that infinitely move in the entire network. Thus, flooding operations should be selectively controlled to assure efficient and useful flooding in the network. Moreover, the frequent link breakages owing to node mobility events affect the network performance, which increases the demand for an effective link failure prediction strategy.

This research aims to propose two main mechanisms, zone-based route discovery mechanism and link failure prediction mechanism, associated with route discovery and route maintenance that form the development in on-demand source routing protocols. The main goal of the zone-based route discovery mechanism is to reduce the overhead incurring by the route discovery process by selectively forwarding RREQs to other nodes in the network, thus maintaining the ability to discover reliable routes. The link failure prediction mechanism (as for route maintenance) aims to predict the current link status to avoid failure conditions and reduce packet loss by utilizing mobility and location information.

Section II discusses several studies conducted to improve the performance of on-demand source routing protocols and particularly of DSR in terms of the route discovery process and link failure prediction strategies along with their limitations. The rest of the paper is organized as follows. Section III presents the proposed mechanisms to enhance the on-demand source routing protocols. The performance evaluation of the proposed work, including a simulation scenario setup, is illustrated in section IV. The performance evaluation and results are discussed in section V. Finally, the conclusion and future work are presented in section VI.

II. RELATED WORKS

This section thoroughly explains the previous research work related to route discovery and link failure prediction mechanisms.

Shobha and Rajanikanth [41] proposed an enhancement called relay routed DSR to reduce the amount of RREQ and control packets. This protocol functions according to the mobility information collected from the neighboring nodes during the flooding phase and uses it to select the relay nodes where RREQs should be sent during the relaying phase. However, the mobility information of a node obtained during the flooding phase might not be valid owing to the speed of the moving node, which causes redundant route discoveries that contribute to more overhead.

Ramesh *et al.* [42] proposed the preemptive DSR (PDSR) protocol to predict the link breakage time using the signal strength of the received packets. In this approach, the source node during the route discovery process builds two routes: the primary route and the backup route. During the communication time, the intermediate nodes on the active route continue observing the received signal strength. If this signal strength drops below the threshold value, then the intermediate nodes send a warning message to the source node. When the source node receives the warning message, it begins using the alternate route, which is the backup route; if this route also fails, the source node starts initiating a new route discovery process. However, PDSR shows slow reaction when the network topology frequently changes because it needs to perform route switching more frequently. The link failure prediction procedure of PDSR to cope with link failures is slow and expensive.

Sultana *et al.* [43] and Kaur and Singh [44] proposed enhanced DSR to improve the performance of DSR by reducing the overhead of RREQ broadcasting through the use of a multicasting approach where in the forwarder nodes rebroadcast the receiving RREQs to the neighbors that are not in the route request option in the RREQ received. However, changes in the number of chosen nodes affects the amount of flooding, and this effect can be significant unless an efficient approach for selecting beneficial forwarders based on, for example, location is used.

Zahedi *et al.* [45] proposed a new approach called modified DSR (MDSR) to fix the problem of link failure, where in each node on the active route monitors the signals of the received data packets of its previous node; when the value of this signal continuously decreases after some consecutive measurements, then the node recognizes that the link will be broken soon and a warning message is sent to the source node, which has to exchange the entire affected route and not only the influenced link. However, MDSR link failure prediction is slow and does not realize route breakage on time. In addition, it generates high control overhead when building a new route that is different from the current one.

Vijayalaxmi *et al.* [21] proposed a mobility prediction algorithm called DSR with link life time (LLT) that aims to reduce packet loss owing to link failures. It calculates the duration of the liveliness of the discovered route, called route life time (RLT), as well as the latency for each discovered route. Latency is calculated by the destination node and included in the route reply (RREP) packet, which will be sent to the source node; then, through the RLT and latency, the source node estimates the approximate number of packets that the route can handle. However, this algorithm suffers from high delay when the number of nodes increases in a route and is therefore not applicable in a high mobility model.

Malwe *et al.* [46] proposed two techniques for reducing the broadcast of RREQ packets and computing the link availability. The first technique is zone-based; here, the transmission range of each node is divided into the inner, middle, and outer zone based on the received signal strength and two predefined thresholds, and only the nodes in the middle zone participate in the route discovery process. The second technique is segment-based; in this technique, the link availability ratio (LAR) for all neighboring links is calculated using the present position of the neighbor and its angular sector in the transmission range. Nevertheless, this algorithm suffers from packet looping and high number of hops toward the destination during the route discovery process. This technique does not consider the direction of nodes in the selected region to ensure the RREQ packet can reach its destination.

Al-Shora *et al.* [47] proposed reliable DSR (RDSR). The goal of the suggested algorithm is to obtain a stable route by extending the route lifetime. In this approach, the format of the RREP packet is updated by adding an extra field for signal strength so that during the route discovery phase, when a RREP packet is received by an intermediate node, it will measure the signal strength of the received packet, called MSS, and compare this value with RSS, which is a high default value of RREP. When MSS is less than RSS, the value of the signal strength of RREP is updated by the MSS value; otherwise, RREP retains its signal strength value without any change. This process will continue until the RREP packet reaches the source node. Finally, the signal strength field of the RREP packet will contain the lowest link quality in the route. In theirs proposed link failure prediction mechanism, the data packet format is modified by adding an extra field for the signal strength of a route, called RSS, into its header. When an intermediate node receives the data packet, it calculates the signal strength of the received packet, called MSS. Next, the MSS and RSS values are compared. If the MSS of a link is less than 0.5 RSS, then a route error message is sent to the source node so that it will search for another route. However, if MSS is greater than 0.5 RSS, then the intermediate node will search the routing table for another route to the same destination with a higher value of RSS. If the route is found, then the data packet is updated with a new route and new value of RSS, the data packet is sent to the next node along the new path, and the source node is informed about this update. Nevertheless, this algorithm may not be efficient owing to the fluctuation of signal strength, and it suffers from consecutive measurements of signal strength that increase the overhead in the network.

In this paper, enhancement mechanisms are proposed for the existing protocols that still suffer from packet looping in the route discovery process and do not ensure route establishment. Another drawback of the existing protocols is the routing overhead as the amount of flooding varies with the number of chosen nodes and this overhead can be significant. Moreover, the existing link failure predication strategies that utilize the signal strength do not function well in high density and are not efficient owing to the fluctuation of the signal strength. In addition, they have high overhead and consume network bandwidth and energy owing to the consecutive measurement of signal strength and continuous updating of the signal information table.

III. PROPOSED MECHANISMS

Two mechanisms are proposed in this research to enhance the on-demand source routing protocols: zone-based route discovery mechanism (ZRDM) and link failure prediction mechanism (LFPM). The design of these mechanisms is presented in the following subsections:

A. ZONE-BASED ROUTE DISCOVERY MECHANISM

The main design motivation behind this mechanism comes from network management and performance perspectives. The ZRDM comprises four main steps: (1) determine the threshold values of zones, (2) classify the neighboring nodes, (3) determine the minimum number of nodes in the forwarding region, and (4) the proposed route discovery procedure. Detailed descriptions of these steps are presented in the following subsections.

1) DETERMINE THE THRESHOLD VALUES OF ZONES

The coverage area with transmission range R is divided into three regions that have been inspired and computed from [48] (as shown in Fig.1) based on the following assumptions shown in Table 1.

The signal strength threshold (*Sstg*) is calculated using the following formula [49]:

$$Sstg = \frac{P_t}{d^{\alpha}\,(4\pi\lambda)^2} \tag{1}$$

Here, d is the distance between the sender and receiver. Pt, λ, and α are the transmitted power, constant, and loss exponent, respectively. In this research, the signal strength threshold values are required to determine the regions; d is substituted by R/2 to find $S_{R/2}$ and by 3R/4 to find $S_{3R/4}$.

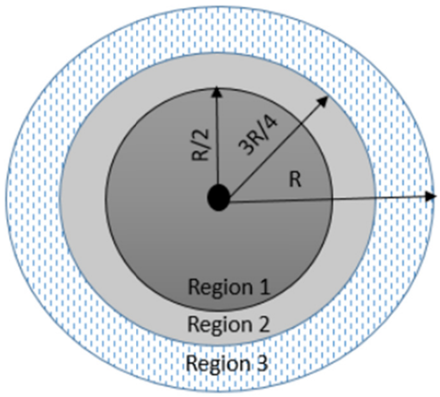


FIGURE 1. Three regions of the transmission.

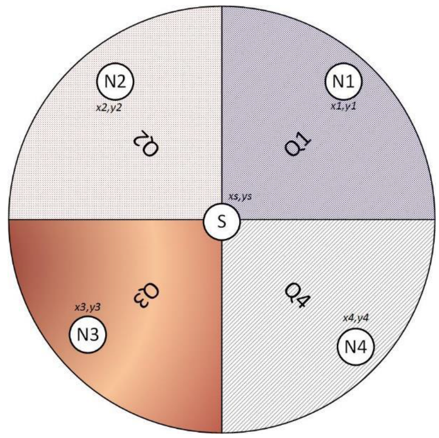


FIGURE 2. Directions of nodes relative to their sender node.

TABLE 1. Data analysis indicator of participants.

Comparison of Sstg with double predefined thresholds (*R/2* and *3R/4*)	Corresponding Region of next hop node
If Sstg > = $S_{R/2}$	Region 1
If $S_{R/2}$ > Sstg > $S_{3R/4}$	Region 2
If Sstg < = $S_{3R/4}$	Region 3

2) CLASSIFY THE NEIGHBORING NODES

Each node maintains a neighboring table and classifies the neighboring nodes into three regions (Region 1, Region 2, and Region 3) based on their location within its transmission range. Every node in the neighboring table is assigned to its corresponding region. Each entry in the neighboring table includes the location and mobility information (speed and direction) of the neighboring node, which is obtained using the global positing system (GPS).

3) DETERMINE THE MINIMUM NUMBER OF NODES IN THE FORWARDING REGION

To avoid packet looping and high number of hops toward the destination, at least one neighboring node in each direction should be available in the selected region to forward RREQ packets; otherwise, the nodes in another region (zone) should participate in the broadcasting of RREQ packets. This process may help ensure that the RREQ packets reach the destination. Considering two dimensions (x, y), the four possible directions are Q1, Q2, Q3, and Q4. Thus, every neighboring node should be associated with its direction in the neighboring table entry. Fig.2 illustrates the possible directions of a node.

For neighboring node i located at (x_i, y_i) and sender node S located at (x_s, y_s), to determine the direction in which the node is located, the following observations can be performed:

If $x_i > x_s$ and $y_i > y_s$, the neighboring node is located in Q1.

If $x_i < x_s$ and $y_i > y_s$, the neighboring node is located in Q2.

If $x_i < x_s$ and $y_i < y_s$, the neighboring node is located in Q3.

If $x_i > x_s$ and $y_i < y_s$, the neighboring node is located in Q4.

Therefore, the sender node will send RREQ packets only to the nodes in Region 3 when this region contains at least one node in each direction; otherwise, the nodes in Region 2 will be involved in the broadcasting of RREQ packets if this region satisfies the above condition, and so on.

4) THE PROPOSED ROUTE DISCOVERY PROCEDURE

The route discovery procedure in a source node that utilizes the proposed strategy is as follows:

- Source node S generates a RREQ packet with a unique ID number. RREQ carries the route record (which contains the full route to the destination node), the destination address, and the source address included in the route record.
- S will forward the RREQ packet to destination node D only if the node is within its transmission range and afterwards D will send RREP back to S, otherwise.
- S has to maintain a neighboring table and classify its neighboring nodes based on their locations in the predefined regions (Region 1, Region 2, and Region 3); therefore, every node in the neighboring table is assigned to its corresponding region. Moreover, each entry in this table includes the location and mobility information of the neighboring node, which is obtained through GPS.
- S has to specify the available neighboring nodes in every region and their directions. The four directions assumed are Q1, Q2, Q3, and Q4 (as explained in Section III.A.3).
- S has to perform the region selection process based on the following assumptions: Region 3 will be selected to forward RREQ packets only when it has at least one neighboring node in each direction; otherwise, to ensure route establishment, the nodes in Region 2 will also be involved in the broadcasting of RREQ packets if the

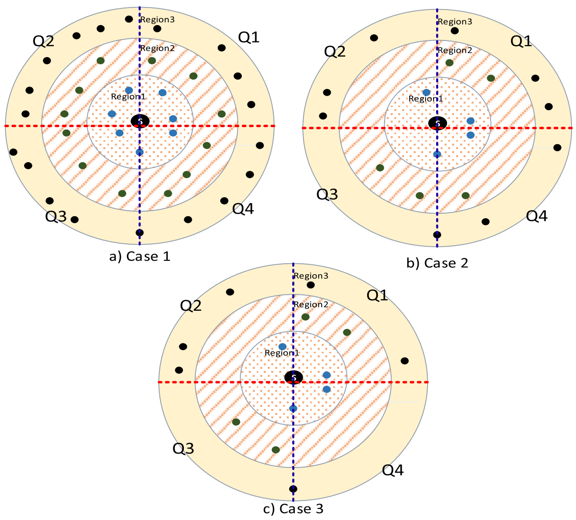


FIGURE 3. Description of the three cases for selecting nodes to forward RREQ.

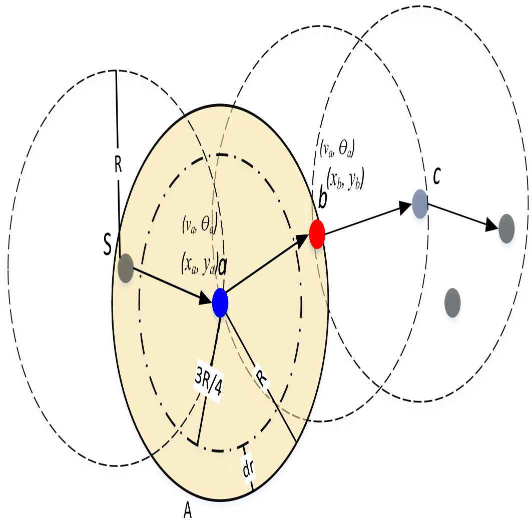


FIGURE 4. Example of the established route between S and D.

above condition is satisfied (the region must have at least one neighboring node in each direction). Else, all three regions will participate in forwarding the RREQ packets.
- When the RREQ packet is received by any neighboring node M of the selected region(s), M will drop the RREQ packet if it has already received that RREQ; otherwise, M will append its address into the route record of the RREQ packet.
- The above procedure will be repeated by any neighboring node M receiving the RREQ packet.

The route between the source and destination will be established once RREP is received from the intended destination. The RREP will be sent to the source node using the full path in route record in reverse order.

To understand the ZRDM at a source node when a new route is required, describing the route discovery procedure is necessary. When a node S is looking for a route to destination D and D is not within its transmission range, node S first has to compute and categorize the neighboring nodes according to their locations in the predefined regions. Next, node S has to determine the available nodes in every region and their directions by applying the rules presented in Section III.A.3. Only the nodes in Region 3 that are near the border and are presented in every direction will receive the RREQ packets to minimize the broadcasting of RREQ packets. This has been given the highest priority to reduce overhead and decrease the number of hops in the path toward the destination.

As shown in Fig.3, three cases explicitly describe how nodes are selected for forwarding RREQ packets:

Case 1. Node density is high and the neighboring nodes are available in all regions and directions; RREQ packets are forwarded to all the nodes only located in Region 3. The same process will be performed at every node that receives the RREQ packet.

Case 2. Few neighboring nodes are located in Region 3 and no nodes are available in Q3. In this case, the nodes in Region 2 will also be involved in forwarding RREQ packets if the nodes are available in every direction. Thus, RREQ packets are sent to all the nodes that belong to Region 3 and Region 2 to ensure route establishment.

Case 3. In this case, no nodes are available in Q4 for Region 3 and Region 2. In this case, all neighboring nodes are involved in broadcasting RREQ packets. This process will be different based on the available neighboring nodes in every direction. Note that the significance of the proposed ZRDM lies in reducing overhead in high-density networks where a number of RREQ packets are only broadcasted to selected neighboring nodes.

B. LINK FAILURE PREDICTION MECHANISM

The LFPM is inspired by the concept of link expiry time (*LET*) and link stability (*LS*). Thus, LFPM utilizes mobility information, node density, the remaining distance to leave the coverage area of the sender node, and Hello message interval. For two connected nodes participating in the active route from the source node to the destination, the sender node should periodically check the connection stability to the next hop mainly in Region 3 for every Hello interval time. These parameters are described in the following subsections.

The proposed LFPM uses predetermined threshold values and mobility information, where the mobility information (speed and direction) of every node is obtained through GPS. The proposed LFPM is triggered when the link to the next-hop node in Region 3 is about to break. Before link failure occurs, the sender node sends an acknowledgment message (ACK) to the source node to initiate a new route discovery process for establishing a new route to the required destination. Fig.4 illustrates an example of the established route (S–a–b–c–D) in DSR between source node S and destination node D. Two connected nodes moving at random speeds and in random directions participate in the active route from the source node to the destination node. Node a is the sender

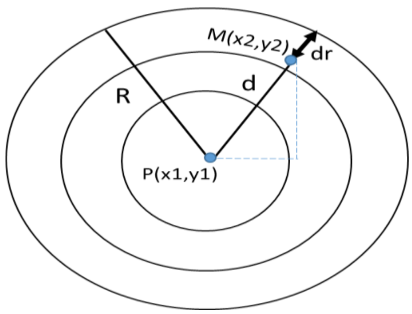


FIGURE 5. Remaining distance threshold.

node; its location coordinates are (x_a, ya) and speed is ($v_a\theta_a$). Node b is the next-hop node; its location coordinates are (x_b, y_b) and speed is ($v_b\theta_b$). *R* is the transmission range, and dr is the remaining distance where node *b* is next-hop of node *a* and in its Region 3.

For designing a mathematical model of link failure prediction for two nodes, a and b, the parameters involved in the design of LFPM are described in the following subsections.

1) REMAINING DISTANCE

The remaining distance *dr* indicates how many distance the next-hop node at which may leave the transmission range of the sender node. Because the location of every node is known owing to the use of the location service, the remaining distance can be computed as follows:

- Determine the distance *d* between the next-hop node M on the active route and its parent node P, where the parent node is the node from which the data packets are received using (2) [50].

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{2}$$

Here, (x_1, y_1) and (x_2, y_2) are the coordinates of the parent node and next-hop node, respectively, obtained using GPS.

- The transmission range *R* of every node can be computed using the signal strength threshold value and error probability, which is usually expressed as bit error rate and is commonly assumed to be 10^{-3} [2], [51]. Thus, the remaining distance, as shown in Fig.5. is calculated by the parent node based on the following equation:

$$dr = R - d \tag{3}$$

- The remaining distance should be determined at the point where the computation of LFPM is triggered when *dr* is smaller than dr_{th}:

Here, 3R/4 is a distance threshold for Region 3.

2) HELLO MESSAGE INTERVAL

All nodes exchange a Hello message with their one-hop neighboring node to update each other with node status information and location coordination in addition to mobility information. Each node in the network that employs ZRDM maintains a neighboring table that holds all neighboring node data (listed by ID, location, and direction) and classifies the neighboring nodes into three regions according to their locations within the node transmission range. The table is updated by broadcasting a Hello message at certain intervals [52]. During the Hello message time interval (T), the sender node can receive the updated information about its neighbors; therefore, involving this parameter in the link failure prediction model is important.

TABLE 2. Node density in different forwarding zones.

Forwarding Zone	Node Density (*ND*)
Region 3	$\frac{16\,N}{7\pi R^2}$
Region 3 &2	$\frac{4\,N}{3\pi R^2}$
Coverage Area	$\frac{N}{\pi R^2}$

3) DETERMINING NODE DENSITY IN THE FORWARDING ZONE

The term forwarding zone (FZ) in this section refers to the selected region as discussed in Section III.A.3 this could be Region 3 only, Region 3 and 2, or the entire coverage area. Node density is computed as the number of nodes per area unit. If Region 3 is the FZ, the node density will be the number of nodes in Region 3 divided by the area of Region 3. Therefore, if the number of nodes in FZ is N, then the node density for the entire FZ is as shown in Table 2.

Based on the research assumption, the forwarding zone has minimum four nodes, one in each direction.

$$ND_{min} = \frac{4}{FZ_{area}} \tag{4}$$

Thus, node density ratio represents the ratio of the minimum number of nodes that should be available in the FZ and the computed node density.

$$density_{ratio} = \frac{ND_{min}}{ND} = \frac{4}{N} \tag{5}$$

In general, the value of node density should increase when the number of nodes in the FZ increases and vice versa. To meet this condition, the fraction of node density (F_{ND}) can be represented as follows:

$$F_{ND} = \begin{cases} 1-\frac{4}{N} & N > 4 \\ 0.2 & N = 4 \\ \frac{0.2}{4-N} & otherwise \end{cases} \tag{6}$$

The value of F_{ND} is considered as 0.2 to avoid zero values in the designed LFPM because the minimum value of F_{ND} is

0.2, that is, when the number of nodes in the FZ is 4. However, when N > 4, 4 is divided by the number of nodes in the FZ and subtracted from 1; otherwise, 0.2 is divided by the difference between 4 and the minimum number of nodes in the FZ.

4) LINK STABILITY

LET plays a key role in the computation of *LS*, which is used to calculate the time during which the connection between two connected nodes can continue without interruption. Hence, *LS* and *LET* can be considered as the main terms in the design of LFPM owing to their significance in determining LLT. The *LET* between two nodes, i and j, is calculated based on the following equation [53]:

$$LET = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \tag{7}$$

With

a= vi cos θi − vj cos θj

b = xi − xj

c = vi sin θi − vj sin θj

d = yi − yj

Here, vi and vj are the speeds and θi and θj are the moving direction of nodes i and j, respectively. (xi, yi) and (xj, yj) are the coordinates of nodes i and j, respectively.

5) DESIGN OF LFPM

The aforementioned parameters can be involved in a mathematical model to calculate *LS* and determine when the parent node can send an ACK message to the source node. To design such a model, the following steps are taken and assumptions are made:

LET for two connected nodes is equal to infinity if both nodes are moving at the same speed and in the same direction. The worst case scenario is if one node has the maximum speed while the other has minimum speed and both nodes move in opposite directions. Therefore, *LS* between two nodes is proportional to the *LET* value. The form of *LS* can be given as follows [54]:

$$LS = 1 - e^{\frac{-LET}{\alpha}} \tag{8}$$

Here, α is constant; this value should be improved to enhance the form of *LS* and to predict link failure. Thus, in this research, *LET* is modified by a combination of the above parameters to help in finding *LS* and for link failure prediction. Besides, *LET* should be aware about when the Hello message time interval T is high, as described above, to avoid out-of-date information about the next-hop node. Therefore, *LET* is inversely proportional to the Hello message time interval. Thus, increasing T may negatively affect *LET* while reducing T enhances *LET*.

To utilize the proposed concept of remaining distance in the LFPM, this concept should be designed to address the following conditions:

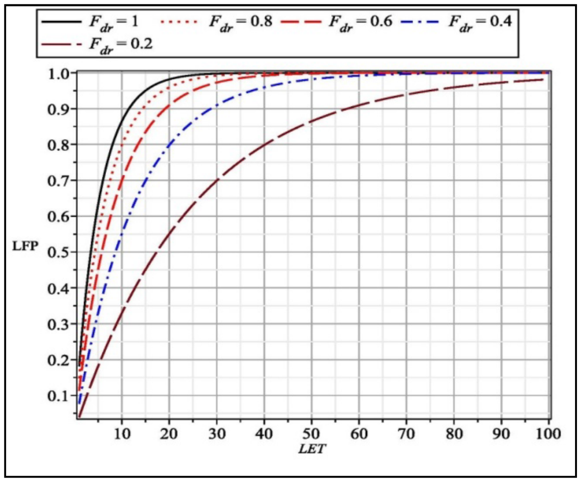


FIGURE 6. The effects of remaining distance on LFP for T=5 s and $F_{ND} = 1$.

- Nodes that are located very close to the border of the coverage area will have very small remaining distance and high possibility of link failure.
- By increasing the remaining distance, the possibility of such nodes going out of range decreases.

To reflect the above conditions, the remaining distance fraction can be represented as a ratio of remaining distance *dr* and remaining distance threshold dt_{th}, as shown below:

$$F_{dr} = \frac{dr}{dr_{th}} \tag{9}$$

This means the nodes far from the border will be assigned with a high value of F_{dr} and the nodes close to the border will be assigned with a low value of F_{dr}.

Now, (8) can be rewritten to represent the mathematical formula of link failure prediction as follows:

$$LFP = 1 - e^{\frac{F_{dr}.LET.F_{ND}}{\alpha.T}} \tag{10}$$

Here, *LFP* indicates link failure prediction; *LET* is computed according to (8), T indicates the Hello message time interval, F_{ND} is the faction of node density, and F_{dr} is the fraction of remaining distance.

Note that the *LFP* value ranges from zero to one [0, 1]. Hence, for the parent node to inform the source node to initiate a new route discovery process, *LFP* should be lower than LFP_{th}. In this research, LFP_{th} is set to 0.5, which represents the midpoint of the range of *LFP* values.

Fig. 6 shows the effects on *LFP* owing to changes in the remaining distance between two connected nodes participating in an inactive route from source S to destination D, where the Hello message interval time is set to 5 s and density is set to 1; the graph shows that the link is most stable when the remaining distance is high and that LFP decreases with decrease in the remaining distance.

IV. PERFORMANCE EVALUATION

To verify the effectiveness of the proposed mechanisms, a random number of sources nodes ranging from 20 to

TABLE 3. The setting of simulation parameters.

Parameters	Values
No. of Nodes	20 - 140
Simulation Area	300 m x 1500 m 1000 m x 1000 m 400 m x 800 m
Simulation Time	200-1000 s
Transmission Range	250m
Mobility model	Random Waypoint
Speed of nodes	0 to 5 m/s 5 to 35 m/s
Pause Time	50 – 500 s
Propagation Model	Free Space Model
Channel Type	IEEE 802.11
Packet Size	512 bytes
Traffic Type	CBR / UDP

140 nodes were simulated using network simulator 3 (NS3), as described in Table 3. Many researchers have validated their work on source routing protocols using NS3 [55]–[57].

These source nodes were configured to send constant bit rate (CBR) data packets and to move randomly at speed accelerating from 5 m/s to a maximum of 35 m/s with random pause times from 50 to 500 s. The transmission range of the nodes was 250 m. For generating random nodes movement, the random way point (RWP) algorithm is used. The simulation period is 1000s, which is sufficient to estimate packet loss, delay, and overhead.

V. RESULTS AND DISCUSSION

The performance of the proposed mechanisms was evaluated by comparing it with standard DSR as well as with recently proposed enhancement of DSR such as RDSR, zone-based DSR and segment-based DSR in terms of packet delivery ratio (PDR), normalized routing load (NRL), and average end-to-end delay. The proposed ZRDM is first integrated as a route discovery mechanism. Then, the LFPM is integrated as a route maintenance mechanism after establishing the active route.

A. EVALUATION OF ZRDM COMPARED WITH DSR

ZRDM is evaluated against variations in the number of nodes. The number of nodes is varied from 20 to 140 to check the impact of increasing number of nodes on the routing overhead and PDR, as described in Table 3. The other parameters are set as follows: the minimum speed is 0 m/s, the maximum speed is 5 m/s, the pause time is set to 20 s, and the simulation time is 600 s. The simulation area is 300 m $\times$ 1500 m. The RWP model is used as a mobility model. The results are evaluated in terms of NRL and PDR and presented in the following subsections.

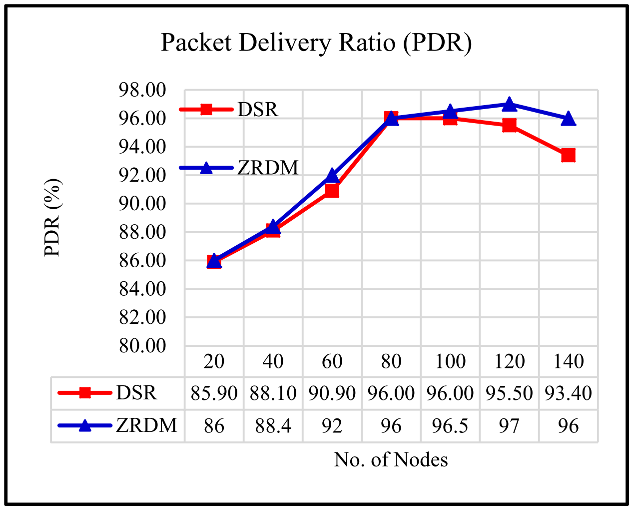


FIGURE 7. PDR of ZRDM compared with the route discovery process used in DSR.

1) EVALUATION OF ZRDM IN TERMS OF PDR

Fig.7 shows the achieved PDR (which is defined as the ratio of the data packets received by the destinations and the data packets sent by the source nodes [44]) of the proposed ZDRM for sending RREQ packets. The results show that when the number of nodes is small, PDR is almost the same mainly at 20 and 40 nodes, where the achieved PDR is 86% and 88%, respectively. This is because the density of the nodes is low and ZRDM selects all the coverage areas for sending the RREQ packet, thus functioning as a standard DSR. By increasing the number of nodes, the probability of enough neighboring nodes being available in Region 3 is high, which decreases of RREQ packets transmission from the neighboring nodes located in Region 1 and Region 2. Thus, the highest improvement for ZRDM compared with the DSR is achieved when the number of nodes is 140; here, the enhancement of PDR is 2.78%.

2) EVALUATION OF ZRDM IN TERMS OF NRL

Fig.8 shows the achieved NRL of the proposed ZRDM, which is defined as the total number of routing packets broadcasted per delivered data packet at the destination. As shown in Fig.8, DSR generates more RREQ packets than ZRDM because every node receives a copy of RREQ that it has to rebroadcast; thus, the number of RREQ packets is particularly high when the number of nodes in the simulated area is more than 60. However, NRL further decreases when the number of nodes is increased. For instance, NRL at 80 nodes is about 11.93% for DSR and 8.10% for the proposed ZRDM, thus showing a decrease of 3.83% compared with DSR. At 120 nodes, the obtained NRL for ZRDM is 18.98%. These results show that the average decrease in NRL for ZRDM is around 32% because it only considers the nodes in Region

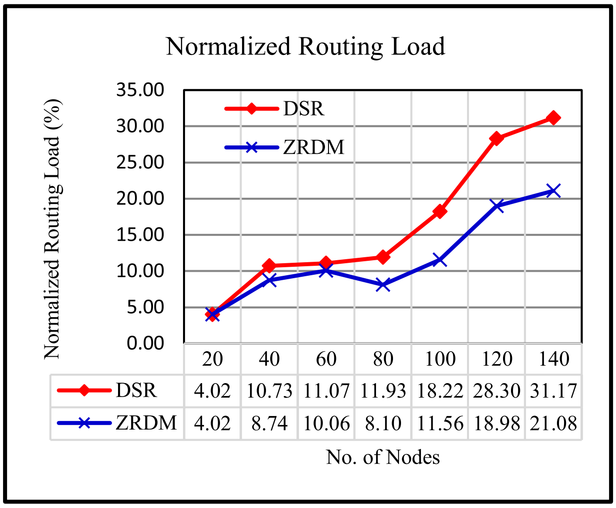


FIGURE 8. NRL of ZRDM compared with DSR.

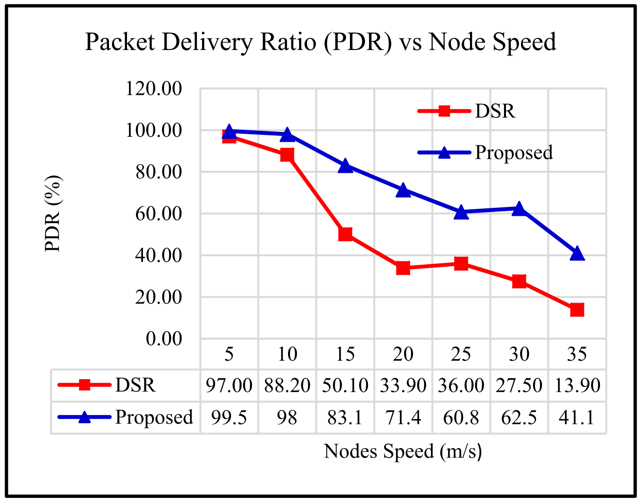


FIGURE 9. Effect of node speed on the PDR of LFPM and DSR (50nodes).

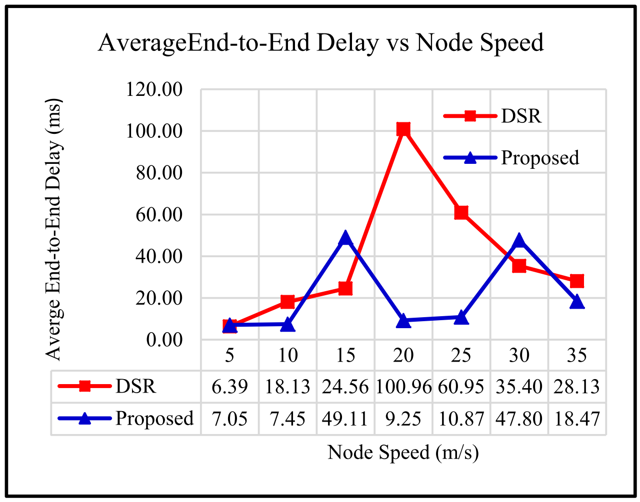


FIGURE 10. The average end-to-end delay for the proposed LFPM compared with DSR.

3 when sufficient nodes are available for broadcasting RREQ packets during route discovery.

B. EVALUATION OF LFPM COMPARED WITH DSR

LFPM is integrated into source routing to improve its performance against the link breakages that result from the mobility in MANET. Thus, LFPM is evaluated by varying the node speeds from 5 to 35 m/s to check the impact of increasing network topology changes during sending packets on the active route. According to the design of LFPM, after an active route is created, if the next-hop node is in Region 3, the sender node starts computing *LS* to avoid link breakages.

The simulation parameters set in this scenario are as follows: the pause time is set to 0 s, which means that the nodes are moving without a stop during the simulation time that is set to 600s. According to the simulation parameters presented in Table 3, the simulation area is 300 m × 1500 m. The RWP model is used as the mobility model for node distribution along the testing area and for assigning the speed of the nodes. The number of nodes in this experiment is set to 50. The following subsections discuss the evaluation results of LFPM in terms of PDR, end-to-end delay, and NRL.

1) EVALUATION OF LFPM IN TERMS OF PDR

As shown in Fig.9, at a speed of 5 m/s, the PDR of the proposed LFPM achieves almost similar results as the standard DSR. By increasing the node speed to 10 m/s, the proposed LFPM achieves better results for PDR compared with DSR, where the PDR achieved using LFPM is about 98% whereas that using DSR is around 88%, showing a 10.20% increase. This is because increasing the speed of nodes may increase the number of link breakages, thus affecting the PDR as in DSR. LFPM improves the routing efficiency by reducing the effects of increasing speed; this is because it considers *LS* in the calculation of link failure prediction along the active route. By increasing the node speed to 15 m/s, the achieved PDR using LFPM is about 83.1% while that using DSR is about 50.10%; the enhancement in PDR is 65.9%. By increasing the speed to 20, 25, 30, and 35 m/s, the PDR drops sharply for both mechanisms; however, the proposed LFPM achieves better results at all tested speed values. The general enhancement in PDR for all values tested in this scenario is about 38.2%.

2) EVALUATION OF LFPM IN TERMS OF AVERAGE END-TO-END DELAY

Indeed, the average end-to-end delay is the summation of the delivery delay of every packet when travelling from source to destination divided by the number of received packets. Fig.10 illustrates that at different speed values, the proposed LFPM achieved better delay than that at 10, 20, 25, and 35 m/s. The results show that LFPM achieved 7.45 ms delay at 10 m/s while DSR imposed packet delay at 18.13 ms, which

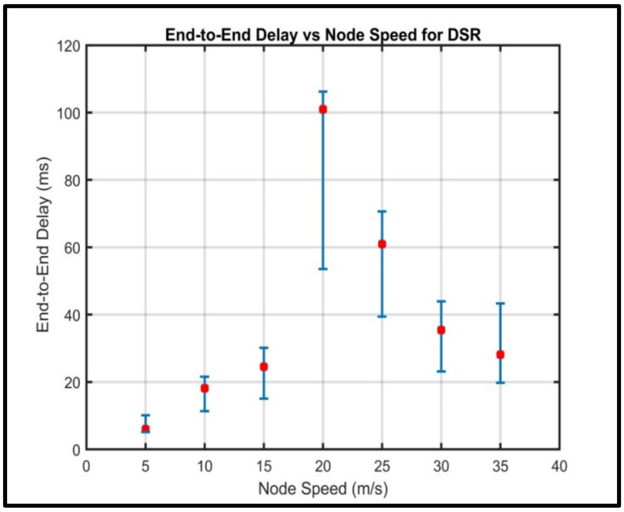


FIGURE 11. Error bar for DSR.

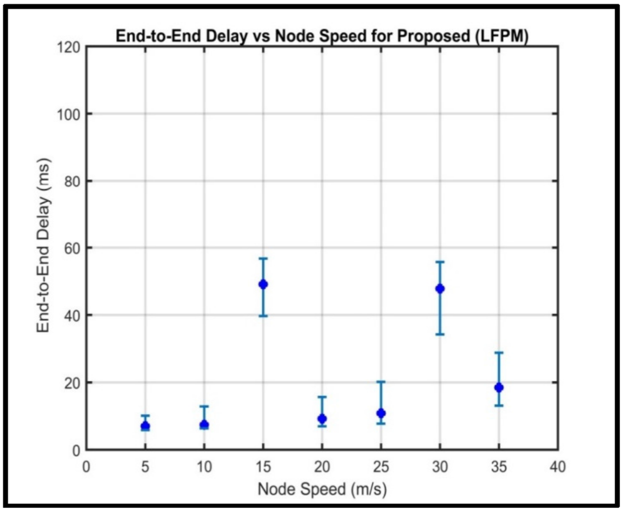


FIGURE 12. Error bar for the proposed LFPM.

is less by about 10.68 ms. The reduction in delay increased with increasing speed of nodes; this is observed at 20 and 25 m/s, where LFPM achieved an average delay of approximately 9.2 and 11 ms, which is lower than that obtained by DSR (100.96 and 60.95 ms, respectively). Moreover, LFPM achieves better delays of about 49.11 and 47.80 ms at 15 m/s and 30 m/respectively, than DSR. This is because the queuing of packets owing to frequent link failures while DSR results in high packet drop, as observed in Fig.9. Upon link failure prediction, LFPM triggers the node to generate an error packet to be sent to the source node to indicate that that a link breakage along this route will happen shortly. Thus, the connection will not be interrupted, and no further delay is imposed on the transferred data.

The error bar for the average end-to-end delay for DSR and LFPM is shown in Fig.11 and Fig.12, respectively.

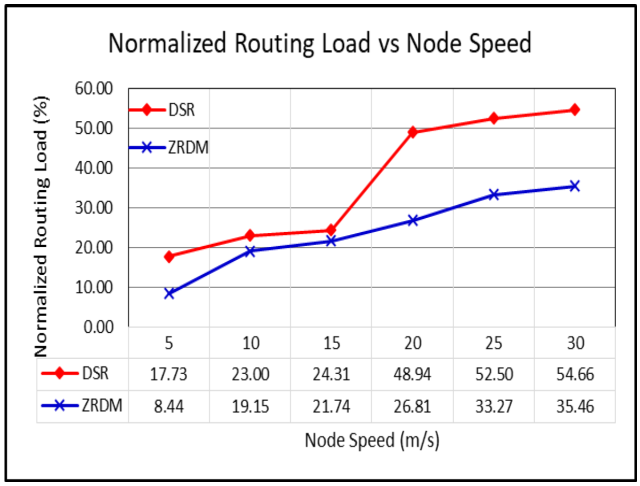


FIGURE 13. NRL results for LFPM compared with those for DSR.

As shown in Fig.10, for both DSR and LFPM, at speeds ranging from 5 to 15 m/s, the average end-to-end delay is close to the minimum value, which means that the majority of the received packets have been delivered to the destination with a minimum delay. From speeds of 20 m/s to 35 m/s, it can be noted that LFPM outperforms DSR because its average end-to-end delay is closer to the minimum value, unlike the DSR whose average end-to-end delay is closer to the maximum value of delay.

3) EVALUATION OF LFPM IN TERMS OF NRL

Fig.13 compares the NRL results for LFPM and DSR by varying the node speed. At a node speed of 5 m/s, LFPM reduced NRL from 17.73% obtained in DSR to 8.44%, showing about 51% reduction. When the speed of nodes increases, the probability of frequent link breakages also increases, thus increase the number of route error messages sent back to the source node to create a new path. Thus, increasing the number of new RREQs by flooding the network with RREQ packets will exponentially increase the routing overhead. Therefore, using the proposed ZRDM helps to reduce unnecessary retransmission, particularly from the neighboring nodes located in Region 1 and Region 2.

Fig.13 shows the significant reduction in routing overhead achieved by increasing the speed of the nodes. At 20 m/s, LFPM achieves 26.81% NRL while DSR achieves 48.94% NRL, thus showing reduction of about 45.19%. At 25 and 30 m/s, the NRL achieved using the proposed mechanism is about 33.7% and 35.5%, respectively. In contrast, the computed NRL achieved by DSR at the same node speed is 52.5% and 54.7%, respectively. Therefore, at 25 and 30 m/s, the proposed mechanism achieved a reduction in NRL of about 31.1% and 36.6%, respectively.

C. COMPARISON WITH RDSR

This section aims to compare the performance of the proposed ZRDM and LFPM with that of RDSR by applying

TABLE 4. **Simulation parameters used to compare ZRDM and LFPM with RDSR.**

Parameters	Values
Number of Nodes	50 nodes
Simulation Time	500 s
Simulation Area	400 m x800 m
Packet Rate	4 Packet/s
Mobility Speed	5 m/s
Pause Time	50-500 s

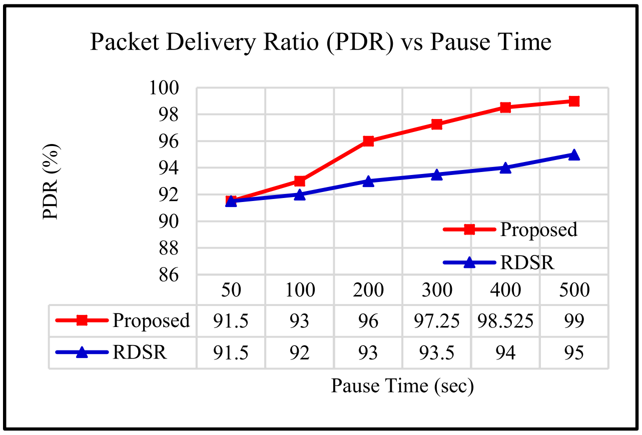


FIGURE 14. **Effects of pause time on the PDR of the proposed ZRDM and LFPM compared with those on the PDR of RDSR.**

the simulation parameters proposed by Al-Shora *et al.* [47], as shown in Table 4. The pause time ranges from 50 to 500 s. At 50 s pause time, the nodes will not move for 50 s, while at 500 s pause time, the nodes are almost static as the simulation time is set to 500 s. The other parameters are set as follows: the node speed is 5 m/s; the simulation area is 400 m $\times$ 800 m. The RWP model is used as a mobility model. The results are evaluated in terms of NRL, PDR, and end-to-end delay.

Fig.14 shows the comparison results of the PDR achieved by the proposed ZRDM and LFPM for source routing and RDSR. From the figure, we note that PDR increases when the pause time increases; however, the proposed work based on ZRDM and LFPM achieved better performance because LFPM is based on mobility information and *LS*, which ensure that the information is updated instead of using signal strength that may give different values owing to the nature of propagation of microwave signals.

In terms of routing overhead, RDSR performs a higher NRL than DSR, which shows that signal strength may not help in making an efficient decision for path selection or use for link failure prediction at the early stages. On the contrary, using mobility information and *LS* concepts can be more reliable to achieve better performance and help nodes to take a proper decision to predict link failure based on updated information.

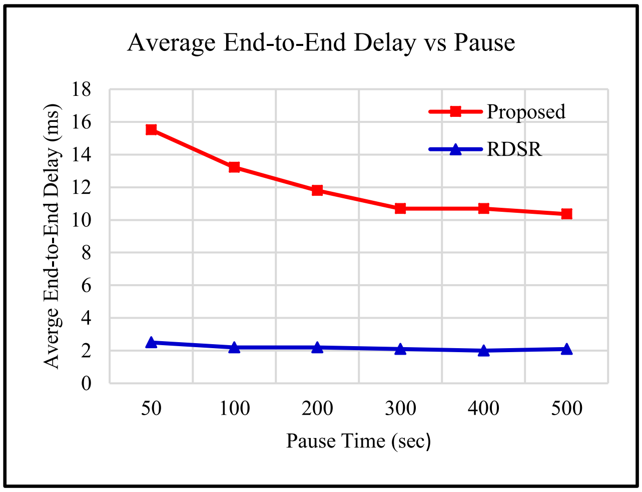


FIGURE 15. **End-to-end delay of the proposed work compared with that of RDSR.**

Fig.15 illustrates the average end-to-end delay of the proposed LFPM compared with that of RDSR at varying pause times from 50 to 500s. The end-to-end delay decreased as the pause time increased. Therefore, the proposed LFPM achieved high delay of about 15 ms when the pause time was 50s; it reduced when the pause time increased because the mobility and probability of link failure decreased. RDSR achieved a very low delay of about 2.5 ms; this may be because the destination is located close to the source and only one hop is required. Also, the proposed LFPM achieved an average delay of 11.7 ms for the tested values of pause time, which is considered acceptable. Indeed, upon link failure prediction, LFPM triggers the calculation only when the next-hop node is located in Region 3 and the error packet is sent back to the source node to indicate that the link may break shortly. Then, the source node should initialize a new route discovery process using ZRDM, as presented earlier. Thus, the connection will not be interrupted, and no further delay is imposed on the transferred data, leading to the expected level.

D. COMPARISON WITH ZONE-BASED DSR AND SEGMENT-BASED DSR

This section presents the comparison results of the proposed solution including ZRDM and LFPM and the zone-based DSR and segment-based DSR proposed by Malwe *et al.* [46]. The evaluation is performed following the same simulation parameters proposed by Malwe *et al.* [46] with varying number of nodes from 20 to 80. Table 5 shows the simulation parameters.

As shown in Fig.16, the proposed ZRDM achieves a reduction in the number of control overhead packets compared with segment-based DSR and zone-based DSR. At 20 and 40 nodes, the proposed work with ZRDM and LFPM achieved a reduction of about 24.22% and 14.3% over both zone-based and segment-based DSR, respectively.

TABLE 5. Simulation parameters used to compare ZRDM and LFPM with zone-based DSR and segment-based DSR.

Parameters	Values
Number of Nodes	20 to 80 nodes
Simulation Time	900 s
Simulation Area	1000x1000m^2
Packet Rate	4 Packet/s
Mobility Speed	20 m/s
Pause Time	0 s

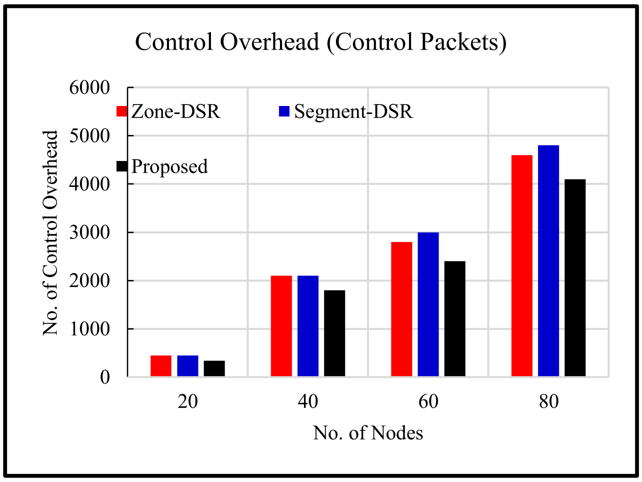
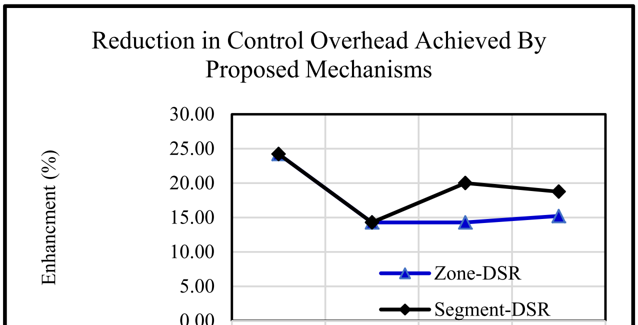


FIGURE 16. Comparison of overhead based on the number of nodes.



	20	40	60	80
Zone-DSR	24.22	14.29	14.29	15.22
Segment-DSR	24.22	14.29	20.00	18.75

FIGURE 17. Reduction of control overhead packets by the proposed ZRDM and LFPM compared with zone-based DSR and segment-based DSR.

By increasing the number of nodes, the control overhead is exponentially increased owing to the higher number of nodes transmitting and retransmitting the control packets. The proposed mechanisms achieved a significant reduction in terms of control overhead, as shown in Fig.16.

For instance, at 60 nodes, the proposed ZRDM and LFPM achieved a reduction of about 20% and 14.3% over segment-based DSR and zone-based DSR, respectively, and the reduction achieved by the proposed mechanisms at 80 nodes is about 20% and 10.9% over segment-based DSR and zone-based DSR, respectively. Fig.17 illustrates the enhancement of ZRDM and LFPM over zone-based DSR and segment-based DSR. The results prove that the use of Region 3 for route discovery helps in reducing the control overhead. Moreover, ZRDM ensures that the available nodes in Region 3 are sufficient for a successful route discovery process, as described before.

VI. CONCLUSION AND FUTURE WORK

In this paper, two mechanisms, ZRDM and LFPM, are proposed and compared with standard DSR and other enhanced works based on DSR such as RDSR, zone-based DSR and segment-based DSR. The evaluation of ZRDM as a route discovery strategy is performed by determining the impact of variations in the number of nodes on the routing overhead. The NRL results show that ZRDM performs well in reducing the routing overhead. These improvements are attributable to the proposed route discovery process used in ZRDM, where the coverage area is divided into three regions(zones) and the highest priority is assigned to Region 3 based on the availability of the minimum number of nodes in the FZ for reducing the number of RREQ retransmissions by the nodes that are located close to the sender. Moreover, using the nodes close to the border can minimize the number of hops toward the destination, resulting in less delay. LFPM is designed for route maintenance to avoid link breakages that can lead to high packet loss. LFPM is evaluated by increasing the speed of the nodes, which leads to rapid topology changes and a high possibility of link failure. The evaluation involved varying the speed of the node and comparing its performance with that of standard DSR. The results showed a significant improvement in terms of PDR and a noticeable reduction in NRL and average end-to-end delay. LFPM uses the mobility information and *LS* concepts to help in the detection of link failure before it occurs, which allows the source node to establish a new route. Furthermore, the proposed mechanisms are compared with two recent enhancement works based on DSR. The results showed that using signal strength to determine link breakages is not efficient because the accuracy of signal measurement may not be reliable, which can lead to an inaccurate decision in link failure prediction. Also, determining the direction and speed of the neighboring node is difficult. Therefore, LFPM is more reliable than existing work for determining the probability of link failure and the LLT for two nodes to stay connected. In future work, the proposed mechanisms will be compared with other standard protocols such as lightweight on-demand ad hoc distance-vector routing protocol – next generation (*LOADng*) and routing protocol for low-power and lossy networks (*RPL*) and combined with multi-disjoint route mechanism to study how well the combination can enhance the quality of service in MANET.

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