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PAPER

Developing Multipath Routing Protocol Based on Source Routing Protocol in MANET

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ABSTRACT

Mobile Ad hoc Networks (MANETs) provide a flexible solution for establishing networks in environments where conventional infrastructure is unavailable, such as disaster areas or military operations. However, routing in MANETs is a critical challenge due to node mobility and limited resources. Numerous protocols have been developed, though their performance varies in various conditions. This study paper introduces a multi-disjoint route technique built on the source routing principle, designed to improve MANET performance for the sake of meeting Quality of Service (QoS) requirements. The performance evaluations of the proposed on-demand multipath source routing protocol using NS-2 in comparison with other DSR-based protocols, namely Modified-DSR, Extended-DSR, and Updated-DSR, the results have suggested that the proposed on-demand multipath source routing protocol has obvious advantages in terms of Packet Delivery Ratio (PDR) and Normalized Routing Load (NRL) over the common existing routing protocols developed for MANET.

KEYWORDS

routing protocols, packet delivery ratio (PDR), normalized routing load (NRL), mobile ad hoc networks (MANETs)

1 INTRODUCTION

The fast improvement of innovation and diminishing costs of sending have made Mobile Ad hoc Networks (MANETs) increasingly viable as a key for on-demand connectivity in environments without fixed infrastructure. The applications of MANETs can be seen in several fields, including (a) disaster recovery: in the event of an earthquake or flood, the affected areas depend on MANETs for rapid and adaptable communication. (b) military operations, where secure, efficient, and robust routing is serious to operation success. (c) IoT and smart city applications, where data transmission is vital for real-time monitoring. (d) autonomous vehicles, where Vehicular Ad Hoc Networks (VANETs) rely on MANET principles for communication between moving vehicles. In MANETs, a group of mobile nodes (see Figure 1) communicates

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without any centralized management [1], [2]. MANETs are used widely across various scenarios, from academy campuses and conferences to army and emergency communications [3], [4], [5].

Fig. 1. Communications in MANETs

In MANETs, intermediate nodes relay data packets from source to destination through a process called multi-hopping [6], [7], [8], [9]. This design allows nodes to function as transmitters, receivers, and forwarders (routers) [10], [11]. Given the critical role of efficient route detection and maintenance, each node significantly influences the network's performance by establishing and sustaining routes between sources and destinations; this is the main challenge to such networks [12], [13]. Frequent link failures caused by node mobility necessitate alternate routes to prevent data loss and maintain communication continuity, ultimately boosting network performance [14], [15], [16], [17]. Thus, dynamic routing protocols that ensure route availability throughout the network's lifespan are indispensable. Multipath routing is one effective approach to increase network capacity and reliability by distributing traffic across multiple paths [18], [19], [20]. However, current multipath routing protocols often generate considerable message overhead through route discovery, caused by increased flooding while multipath is of concern in these protocols. This study proposes an enhanced multi-disjoint path mechanism designed to enhance routing in MANETs. This paper is prepared as follows: Section 2 depicts commonly used multi-hop routing protocols designed for MANETs. Section 3 reviews multipath routing protocols in MANETs, identifying their limitations. Section 4 introduces the proposed Multi-Disjoint Paths mechanism, Section 5 describes performance evaluation results, and Section 6 reviews the conclusion and future work.

2 COMMON MULTIPLE HOP ROUTING PROTOCOLS FOR DATA DELIVERY IN MANET

Multipath routing protocols in MANETs focus on discovering multiple paths and maintaining these routes. By distributing data traffic across multiple routes, these protocols aim to improve data transmission reliability. Hence, providing various routes is advantageous in MANET's communications, where routes are subject to frequent failures due to node mobility and poor quality of wireless links [21]. Due to its adaptive response to network changes, reactive (on-demand) routing has been extensively studied and applied. Among these, the Ad hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) protocols have gained significant attention [22].

On-Demand Distance Vector is a prominent routing protocol invented for MANETs. Unlike traditional routing protocols that maintain consistent routing information across the network, AODV establishes routes only when needed, reducing the overhead associated with continuous route maintenance [23], [24]. The major advantage of AODV is its scalability and efficiency, making it proper for mobile environments where bandwidth is restricted and nodes are subject to frequent disconnections [25]. However, AODV also faces challenges, including vulnerability to route breakage and increased latency in highly mobile networks. Despite these challenges, AODV remains a widely used protocol due to its adaptability and performance in diverse network scenarios [26], [27].

Dynamic Source Routing [11], [22], [27], [28] is a widely nused reactive protocol with two main processes: route finding and route maintenance. When a transmitting node requests a route to a destination that is not stored in its routing table, it introduces the route detection process, which relies on network-wide flooding. RREQ packets move across the network, searching for a path between source and destination nodes. Once the destination is reached, a Route Reply (RREP) is returned to the source node. All discovered routes are then stored in the nodes' caches. This route discovery process, however, creates high control overhead, which can degrade network performance [29]. When a connection on an active path break, the route maintenance method initiates a Route Error (RERR) message to return back to the source to signal the need for a new route.

3 RELATED WORKS

Different multipath routing protocols have been improved to address the challenges of single-path protocols, such as limited throughput, high latency, and network overhead. This part reviews the existing research work that provides valuable enhancements to the basic DSR and associated multipath routing protocols, which propose to improve MANET routing efficiency, and highlights their limitations.

Ahn [30] proposed the Extended-DSR protocol that incorporates multipath routing extensions to the standard DSR to improve reliability and load balancing. While this approach reduces the risk of packet drops by utilizing multiple disjoint paths, it introduces significant complexity in route discovery and maintenance. The need to maintain and manage multiple routes increases the protocol's overhead, especially in dense networks. Moreover, the protocol may struggle to ensure consistent performance under conditions of high node mobility, as frequent topology changes can render multiple cached routes invalid, leading to additional route rediscovery efforts and delays.

Mandhare and Thool [31] proposed the Updated-DSR protocol that introduces a cache update scheme aimed at enhancing the Quality of Service (QoS) in MANETs. While this approach effectively reduces stale route entries and improves overall routing accuracy, it suffers from several limitations. The frequent updates to the route cache result in increased computational and communication overhead, which can strain resource-constrained MANET nodes. Furthermore, in highly dynamic scenarios, the reliance on cache updates alone may not be sufficient to mitigate frequent link breakages, leading to delayed route recovery and higher packet loss rates.

Acharekar et al. [32] proposed the Modified-DSR protocol, which emphasizes improving performance in both mobility and non-mobility scenarios. Although it enhances routing efficiency by optimizing route selection and management, the protocol demonstrates limitations under high-mobility conditions. The increased control overhead from the additional mechanisms used for route improvement can degrade performance when the network topology alters quickly. Additionally, the protocol's reliance on optimized route discovery and maintenance processes may lead to scalability challenges in large-scale MANETs, where the number of nodes and connections exponentially increases.

Ghaleb and Vasanthi [33] introduced Multi-Objective Grey Wolf Optimization (MGWO)-based DSR protocol by proposing an energy-efficient multipath routing protocol that integrates the Multi-Objective Grey Wolf Optimizer with the DSR algorithm. The protocol aims to optimize path choice built on energy consumption and link stability. The integration of the optimization algorithm introduces computational complexity, which increases the overall routing overhead in route detection and maintenance phases.

Chandravanshi et al. [34] proposed Adaptive Multipath Multichannel (N-channel) Energy Efficient (MMEE), which that introduces an adaptive multipath N-channel routing method for MANETs, focusing on energy proficiency, load balancing, and bandwidth awareness. However, its high control overhead and potential delays from complex routing operations may challenge scalability and responsiveness in highly dynamic or resource-constrained MANET environments. Future work could focus on reducing overhead through simplified path selection or clustering techniques to enhance scalability and overall performance.

Lavanya et al. [35] offered the Mobility-Based Optimized Multipath Routing Protocol (MBOMRP), which presents an MBOMRP that selects the best links based on node mobility patterns to enhance route stability and performance in MANETs. However, the protocol's reliance on frequent mobility predictions adds to computational and communication overhead, especially in networks with high node density.

Bhavadharini et al. [36] suggested a Bi-directional Long Short-Term Memory (Bi-LSTM) neural network modified by the Adaptive Horse Herd Optimization (AHHO) algorithm as part of an obstacle-aware routing protocol for MANETs. However, for MANET nodes with limited resources, the high level of computation brought about by combining Bi-LSTM with AHHO may be an issue, potentially impacting scalability and real-time performance.

Yadav et al. [37] proposed the Stable On-Demand Multiple-Path Routing Protocol (SODRP) to increase packet delivery ratio, degrade delay, and reduce control overhead by choosing stable and effective routes in the network. However, SODRP did not explicitly highlight the NRL metric; lack of NRL analysis causes a gap in comprehensively rating the protocol's scalability and productivity.

ul Hassan et al. [38] proposed machine learning models that anticipate and choose the most reliable multipath routes, lowering overhead and improving packet delivery rates, by utilizing deep neural networks and reinforcement learning. However, these methods demand extreme computational resources, leading to greater latency and storage overhead.

Rathod and Kotari [39] proposed a hybrid approach merging cryptographic techniques with multipath routing to increase the security and effectiveness of message transmission in MANETs. However, the increased computational overhead connected with hybrid cryptographic techniques may impact the whole performance.

Abujassar [40] presented an improved Dynamic Source Multipath Routing protocol designed to increase adaptability and energy efficiency in IoT contexts with different node densities. However, the protocol's performance under high mobility and changing traffic patterns is yet unknown, and the study concentrates on limited mobility scenarios, which might not accurately reflect real-world MANET situations.

4 MULTI-DISJOINT ROUTES MECHANISM

The benefits of using multiple paths for exchanging data from a sender to a target have led to the development of an on-demand, destination-oriented mechanism based on source routing. This approach aims to improve routing in MANETs by establishing multiple disjoint paths between the source and destination to guarantee successful delivery of data packets and to provide alternative routes that do not share intermediate nodes in case of route failure.

a) Conceptual overview

- **Source node (S)**

  Once a source node (S) needs to convey data to a specific destination (D), it performs the following actions:

  1. Creates an RREQ packet containing a unique ID, its address, and a timestamp (time of forwarding RREQ).
  2. Spreads the RREQ to all neighboring nodes inside its communication range.
  3. Upon receiving RREP packets, it uses the corresponding route to transmit data.
  4. If multiple RREPs for the same RREQ are received, the information is distributed across these paths based on their Round Trip Time (RTT), which is the amount of time a data packet needs to go from its source to its destination and back again to the source [41]. The destination node D must record the time it receives the RREQ so that node S is informed of the duration it took for the RREQ to get to node D along that specific route. This information allows node S to determine the optimal amount of data to be transmitted upon each of the available routes.

- **Intermediate node (M)**

  Any intermediate node (M) in the network can forward or respond to an RREQ packet. Its behavior depends on its role:

  - If M is the destination, it responds directly with an RREP.
  - If the destination is inside M's transmission range, it forwards the RREQ directly to the destination only to prevent unnecessary propagation over the whole network. Such a technique can subsequently reduce the overhead of traffic load.
  - Else, M updates the RREQ (packet header) with its address and rebroadcasts it.

- **Destination node (D)**

  The destination node (D) determines the routes to be utilized for data transfer between the source node (S) and itself. Primarily, the number of routes must be stated, with four routes being identified as the optimal choice for enhancing overall network performance. Node D is organized to send a maximum of four RREP packets corresponding to four broadcasts of the same RREQ packet. Each RREP packet is assigned a unique number, and node D's cache stores all the accepted disjoint routes to the source node (S). The actions of node D are as follows:

- Upon receiving an RREQ packet, node D checks its cache for an existing route back to the source node (S).
- If a route exists, it uses this route to send an RREP packet.
- If no route is found, D assumes the RREQ packet has arrived via the optimal and shortest path. It keeps this route and indicates to it to accomplish the following decisions for the next 400 msec when another RREQ packet reaches since the initial Time to Live (TTL) for an RREQ packet is 500 msec, after which retransmission occurs if no RREP is received). TTL is a value set in the header of each data packet when it is initially generated. The TTL value is decremented by one every time the packet passes through a node. The primary purpose of TTL is to prevent data packets from circulating endlessly due to routing errors or network loops, which can overload network resources [42].
  1. Assign numbers to routes based on the order of their arrival.
  2. Designate the first route (route #1) as the reference route.
  3. Compare route #1 with other routes in the list.
  4. Eliminate routes that share one or more nodes with route #1.
  5. Renumber the remaining routes in the list.
  6. Select route #2 as the new reference and repeat the process until all routes are node-disjoint.
- For each established disjoint route, node D records it in the cache and unicasts an RREP packet back to source node S.

b) Scenario operation

This section illustrates the function of the suggested multi-disjoint routes mechanism in a network scenario. Let's consider that mobile nodes are linked and connected, corresponding to the scenario shown in Figure 2. The source node, node S, needs to direct data to destination node D.

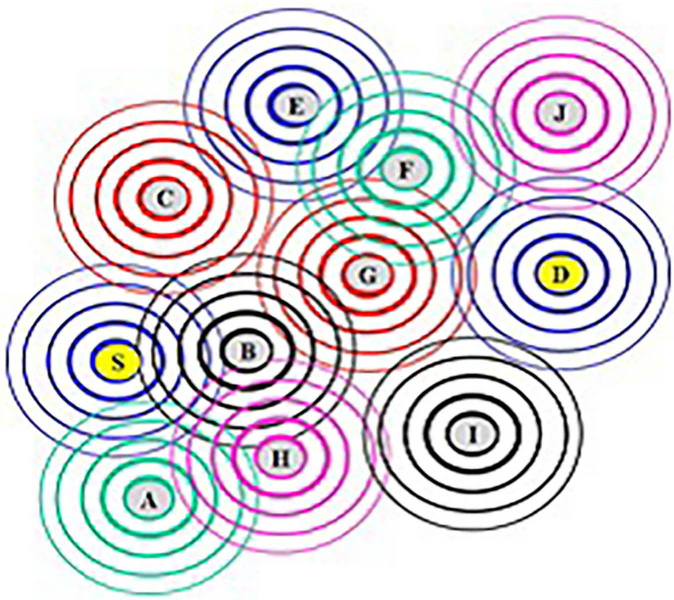

Fig. 2. Scenario of a MANET operation

1. **Initial route discovery:** Node S creates an RREQ packet to initiate the search for a path to node D. The RREQ packet involves information such as the source

node ID, the timestamp, and a unique ID for the request. Node S then disseminates this packet to its neighboring nodes, such as (node C, node B, and node A). In a traditional routing protocol, each of these neighboring nodes would forward the RREQ packet further to their neighbors, eventually reaching node D, as illustrated in Figure 3.

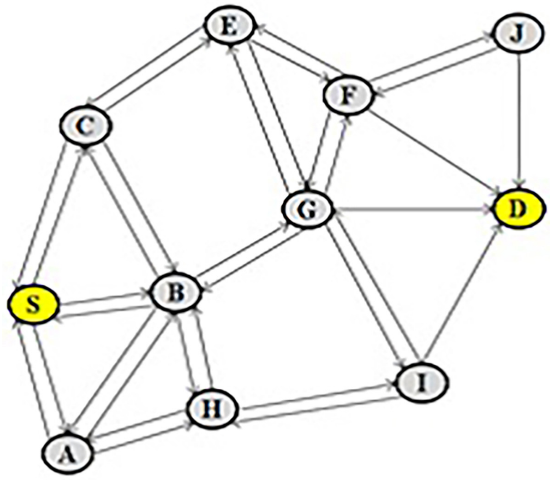

Fig. 3. RREQ broadcast in the network

However, in the multi-disjoint route scenario, node D is designed to receive multiple RREQ packets from different routes and consider them separately to form disjoint paths.

2. **RREQ Propagation and Multiple Routes:** Assume that node D obtains the first RREQ packet from node S via the route {S-B-G-D}, as depicted in Figure 3. Node D considers this path as the shortest and most direct route to node S, marking it as "route #1." While node D is processing this route, other RREQ packets from node S arrive within the next 400 msec via alternate paths; multiple versions of the same RREQ packet reach across the routes illustrated in Figure 4.

route#2 = {S-C-E-G-D}
route#3 = {S-B-G-F-D}
route#4 = {S-B-H-I-D}
route#5 = {S-A-H-I-D}
route#6 = {S-C-E-F-J-D}
route#7 = {S-C-B-G-D}
route#8 = {S-A-H-I-G-D}
route#9 = {S-B-G-I-D}
route#10 = {S-A-B-G-D}
route#11 = {S-C-E-F-I-D}

Fig. 4. Possible routes for the same RREQ directed by node S

Each of these routes is compared against the previously recorded routes to eliminate any overlapping or common nodes.

3. **Route Comparison and Elimination:** Upon receiving the new RREQs, node D compares each new route with the previously stored route (route #1) to ensure the paths are disjoint, as shown in Figure 5.

route#2 = {S-C-E-G-D} remove
route#3 = {S-B-G-F-D} remove
route#4 = {S-B-H-I-D} remove
route#5 = {S-A-H-I-D} keep and update#
route#6 = {S-C-E-F-J-D} keep and update#
route#7 = {S-C-B-G-D} remove
route#8 = {S-A-H-I-G-D} remove
route#9 = {S-B-G-I-D} remove
route#10 = {S-A-B-G-D} remove
route#11 = {S-C-E-F-I-D} remove

Fig. 5. Routes omission

For example, when comparing route #1 ({S-B-G-D}) with route#5 {S-A-H-I-D}, node D checks for common nodes and finds that there are none. Similarly, it compares route #1 with route#6 {S-C-E-F-J-D}, and no overlaps are found either. Based on this comparison, node D eliminates any routes that share common nodes with the existing ones. This results in three disjoint routes being stored in node D's route cache:

- Route #1 = {S-B-G-D}
- Route #2 = {S-A-H-I-D}
- Route #3 = {S-C-E-F-J-D}

Node D then assigns a number to each route, with route #1 being the reference route, and prepares to send RREP packets to node S.

4. **Unicast RREP Packets:** Node D unicast transmits an RREP packet back to node S for each of the disjoint routes. These RREP packets contain information about the routes and help node S identify the best paths for data transfer. As shown in Figure 6, each RREP packet travels along a unique path to reach node S.

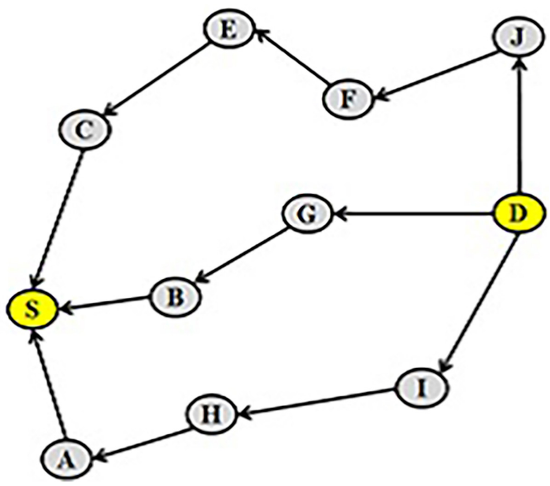

Fig. 6. RREP packets sent by node D to node S over disjoint routes

5. **Data Transfer Over Disjoint Routes:** Once node S receives the RREP packets for the disjoint routes, it uses the acquired routes to send data to node D, as depicted in Figure 7. The data is distributed over the three disjoint routes based on the RTT of each route, regardless of the number of hops along each path. The route with the shortest RTT gets a larger share of the data to maximize the overall network performance.

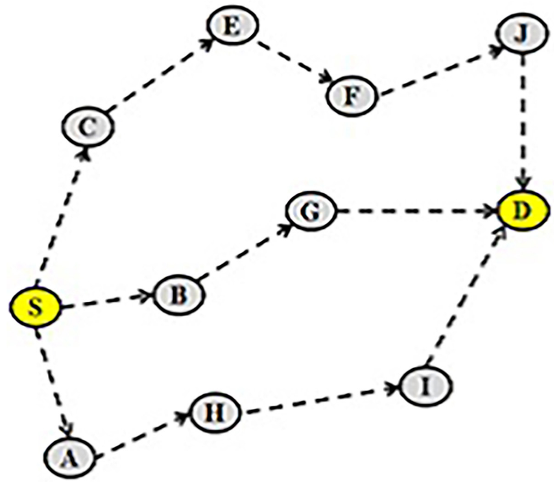

Fig. 7. Transmission of data across the established disjoint routes

5 EVALUATION OF THE PROPOSED ON-DEMAND MULTIPATH SOURCE ROUTING PROTOCOL

This section exhibits the performance evaluation of the proposed on-demand multipath source routing protocol with MDP_DSR mechanism built on the numerical results of the evaluation experiments. The performance is assessed and compared to that of other well-known source routing protocols that is based on DSR and that share same objectives, namely Updated-DSR, Modified-DSR, and Extended-DSR, and according to the Packet Delivery Ratio (PDR), Normalize Routing Load (NRL) evaluation metrics as presented in the following subsections. The experimental data reported here primarily for node speed of 1 m/sec (3.6 km/h) which simulates the speed of a pedestrian, 8 m/sec (28.8 km/h) which simulates the speed of a fast bicycle, and 25 m/sec (90 km/h) which simulates the speed of a car, respectively. Also, experimental data was reported for the pause time values of 0, 20, 40, 80, 160, 300, and 600 respectively.

5.1 Protocol performance – packet delivery ratio (PDR)

This subsection discusses the outcomes of the simulations and highlights the comparative performance of the proposed on-demand source routing protocol, Modified-DSR, Extended-DSR, and Updated-DSR protocols in terms of PDR. Figure. 8 offers an evaluation of how these routing protocols perform under the aforementioned pause time values with a node speed of 1 m/sec. It is noticeable that all of the routing protocols can provide a large quantity of data packets when the node mobility is low. However, irrespective of the pause time rate, the proposed on-demand source routing protocol managed to produce (on average) over 98.6% of its data packets, surpassing the rest of the protocols. When the pause time is zero (presenting the highest mobility), Updated-DSR performs better than Modified-DSR and Extended-DSR, where it delivers about 96% of its data packets; nonetheless, its performance fluctuates sharply as the pause time rate increases. On the other hand, Modified-DSR shows smooth and gradual improvement as the pause time rate increases, outperforming Extended-DSR and Updated-DSR significantly for the pause time values of 40 and above. Compared to Updated-DSR, Extended-DSR oscillates less aggressively and offers a much higher delivery ratio when the nodes pause for a longer time, specifically at 600 seconds. It is due to packet drops of Updated-DSR as a result of stale records in nodes routing tables causing broken routes.

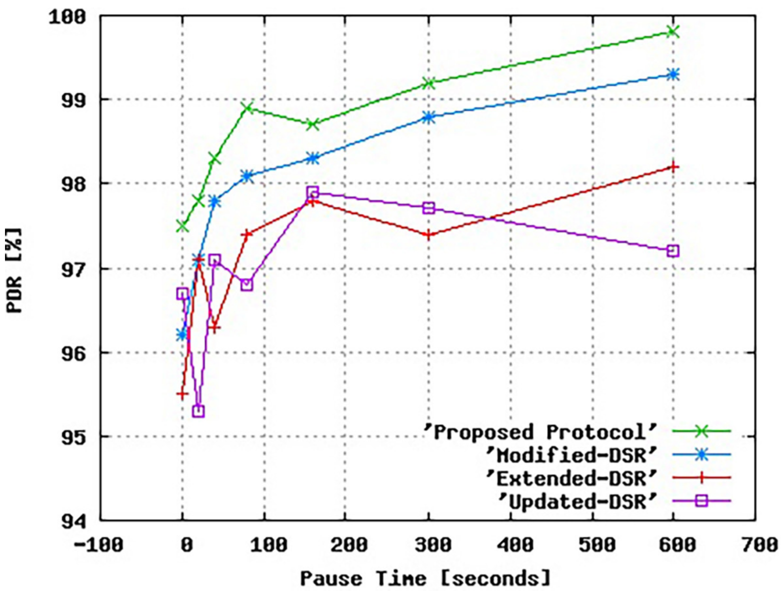

Fig. 8. PDR with node speed of 1 m/sec

Figure 9 presents the PDR for the same pause time values mentioned above with a node speed of 8 m/sec. From the results in the Figure 9, it is obvious that the proposed on-demand source routing protocol dominates the others for the entire range of pause time values. Compared to Extended-DSR and Updated-DSR, Modified-DSR presents better performance, offering higher PDR when node mobility gets lesser and lesser. It shows closer results to the proposed routing protocol when the pause time is 80 and above. However, for low pause time values, the performance of other protocols falls way behind the proposed routing protocol. The results in the figure confirm that the proposed routing protocol presents steady performance for higher mobility scenarios in terms of PDR.

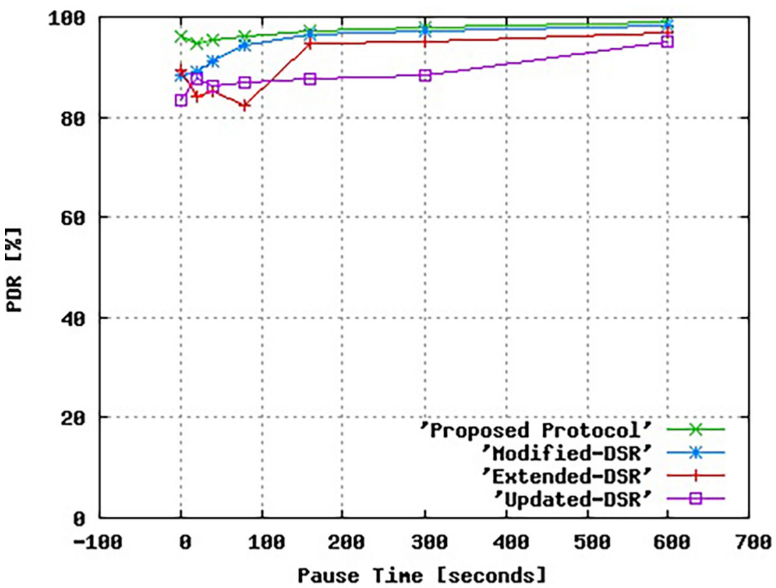

Fig. 9. PDR with node speed of 8 m/sec

Figure 10 presents the PDR for the same aforementioned values of pause time with a node speed of 25 m/sec. It is obvious that the proposed routing protocol presents considerably better performance compared to Modified-DSR, Extended-DSR, and Updated-DSR. The results confirm that the PDR offered by the proposed routing protocol is much higher than the rest of the protocols when the node speed is high. This can be counted for the usage of multiple paths in the proposed routing protocol. Compared to Updated-DSR, Extended-DSR shows better performance for pause time values of 80 and above, presenting closer behavior to that of Modified-DSR, especially for 300 seconds and 600 seconds pause times. Updated-DSR shows the worst performance among the rest of the protocols, confirming its unsuitability for MANETs with highly mobile and fast nodes. Although Modified-DSR comparably outperforms Updated-DSR and Extended-DSR as it exhibits higher and near-steady PDR, it is lower than to that of the proposed protocol, delivering on average about 83% of the data packets, while the proposed routing protocol successfully delivered 92% of its data packets, indicating that Modified-DSR falls short in achieving higher PDR compared to the proposed protocol under conditions of increased node mobility. Both Modified-DSR and Extended-DSR struggle to adapt effectively to topology changes when node pause times are lower.

5.2 Protocol performance – normalized routing load (NRL)

This subsection discusses the outcomes of the performance evaluation experiments of the proposed on-demand multipath source routing protocol in terms of NRL and in comparison with Modified-DSR, Extended-DSR, and Updated-DSR protocols. Figure 11 presents the NRL for these routing protocols when node speed is 1m/sec for different pause time values. From the results shown in the Figure 11, for all of the routing protocols, NRL is reduced as the pause time rate increases, reaching its lowest value when the pause time is at its highest (600 seconds). The proposed routing protocol submits lower overhead caused by its settled multiple routes afforded for transferring data.

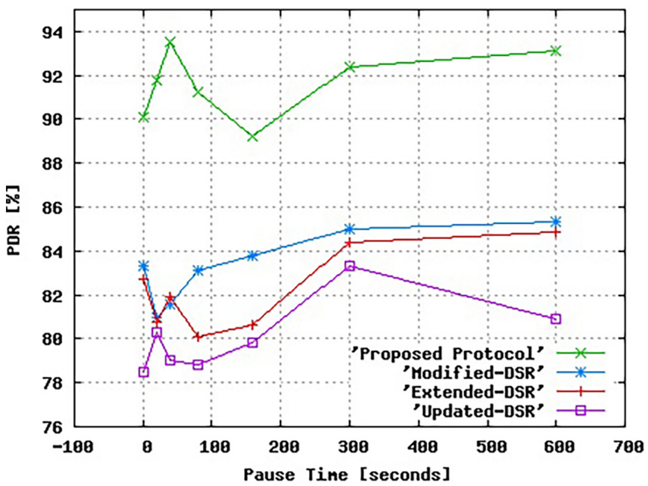

Fig. 10. PDR with node speed of 25 m/sec

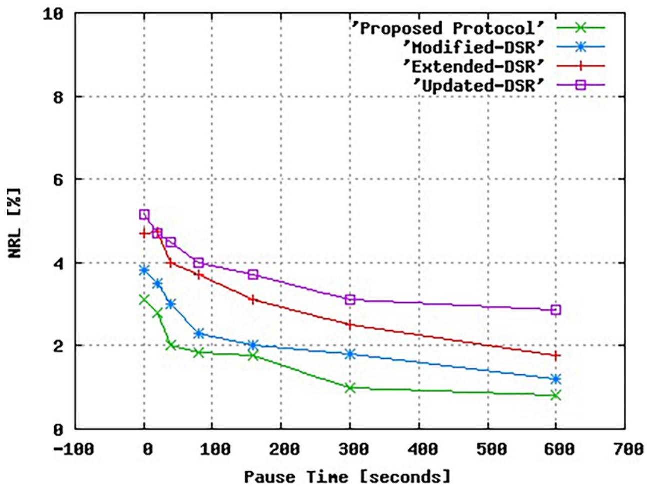

Fig. 11. NRL when node speed is 1 m/sec

The NRL of the proposed protocol is about 3 when nodes are highly mobile (at pause time 0 second), and decreases to 2.8, 2, 1.85, 1.77, 1, and 0.8 for 20, 40, 80, 160, 300, and 600 seconds of pause time, respectively. On the other hand, Updated-DSR offers the highest NRL among the rest of the protocols, except that when the pause time is 2 seconds, Extended-DSR presents a slightly higher NRL of 4.75; after that, it reduces gently as the pause time of nodes increases. Modified-DSR offers better NRL compared to that of Extended-DSR and Updated-DSR, where the observed NRL at high mobility is 3.8.

Figures 12 and 13 show the NRL observed for the aforementioned pause time values when node speed is 8 m/sec and 25 m/sec, respectively. From Figure 12, it is clear that the NRL presented by Modified-DSR, Extended-DSR, and Updated-DSR is higher than that of the proposed routing protocol and fluctuates over different pause time values, while the NRL offered by the proposed routing protocol decreases smoothly. The reason behind such fluctuation can be due to the instability of routes due to several route breakage events that occurred on the active routes. The graph in Figure 13 verifies that for higher node velocity, the proposed routing protocol still maintains lower NRL compared to the other protocols, implying that when node speed increases, the rest of the protocols are not able to handle the fast and regular changes in the network topology. The Figures 11, 12, and 13 reveal that the compared protocols exhibit higher NRL at lower pause times due to frequent link failures, whereas the proposed routing protocol demonstrates better performance. The results further present that the NRL of the proposed protocol increases slightly with rising node velocity but decreases as the pause time grows longer.

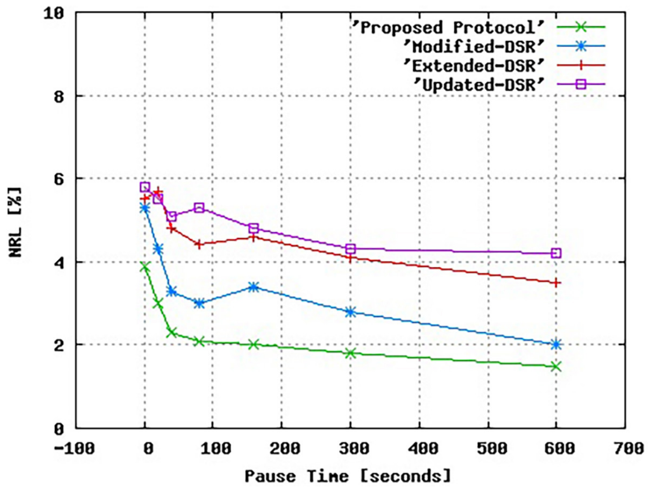

Fig. 12. NRL when node speed is 8 m/sec

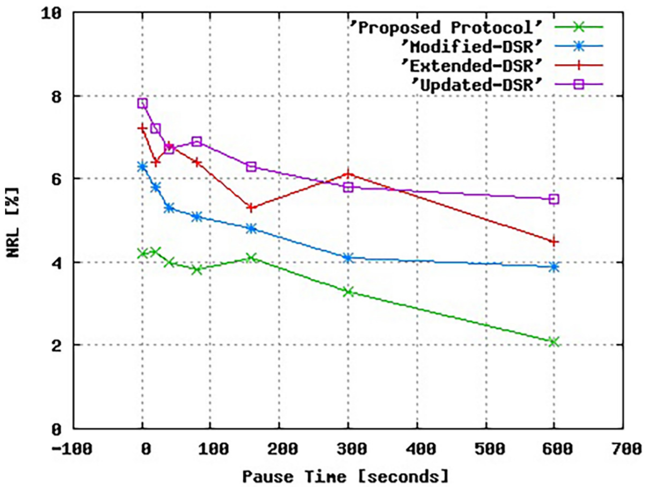

Fig. 13. NRL when node speed is 25 m/sec

6 CONCLUSION AND FUTURE WORKS

Mobile Ad Hoc Networks represent a crucial technology with a promising future, offering flexible and robust networking solutions for various scenarios. Their significance stems from their ability to provide temporary connections in abnormal situations or events. Despite their advantages, MANETs face significant challenges caused by network topology changes due to the dynamic features of MANETs, leading to interruptions in connections and degraded network performance. To address this issue, an effective routing protocol with multiple routes is established between communicating nodes to enhance network performance. When an active route fails, alternative routes can seamlessly take over, ensuring reliable communication.

This paper introduces a MDP mechanism integrated with the DSR protocol to improve routing in MANETs. However, existing on-demand multipath routing protocols often suffer from several limitations, including excessive control packet overhead, limited data transmission rates, and degraded performance with increased node density. The MDP mechanism addresses these challenges by ensuring reliable data delivery and higher throughput while minimizing routing overhead. Performance evaluation results indicate that the proposed protocol with the MDP mechanism is highly suitable for dynamic MANETs. By establishing robust multi-disjoint routes for data delivery, MDP significantly improves routing efficiency in MANETs. Future research could include empirical performance evaluations comparing MDP with other reactive, proactive, and hybrid routing protocols. Moreover, the potential application of MDP in other scenarios, such as VANETs and Mobile Wireless Sensor Networks (MWSNs), presents exciting opportunities for further exploration.

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