A new algorithm for quality-of-service improvement in mobile ad hoc networks

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ABSTRACT

The quality of service (QoS) in mobile ad hoc networks (MANETs) plays a crucial role in optimizing overall network resource utilization. MANET routing protocols, fundamental to QoS, demand adaptive and swift solutions for efficient path searching. In this context, our paper introduces a novel algorithm based on MANETs, employing a hybrid approach that combines ant colony optimization (ACO) with hybrid multipath quality of service ant (HMQAnt) routing protocols. Our algorithm emphasizes bandwidth optimization as a pivotal factor for providing effective paths. By incorporating bandwidth as a significant parameter in the MANETs algorithm, we aim to enhance its overall properties. The proposed routing protocol, focusing on bandwidth optimization, is anticipated to improve the delivery of total network traffic. Evaluation of the algorithm's performance is conducted through QoS metrics, which are overhead, end-to-end delay, and jitter, throughputs, utilizing a MATLAB simulator. Simulation results indicate that our proposed routing protocol holds a distinct advantage compared to ad hoc on-demand distance vector (AODV), destination-sequenced distance (DSDV), dynamic source routing (DSR), and hybrid ant colony optimization-based (ACO) routing protocol called (ANTMANET) algorithms.

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1. INTRODUCTION

Recent years have witnessed increasing interest with mobile ad hoc network (MANET) routing algorithms [1]. MANET, characterized by an interconnected system of mobile wireless nodes, facilitates communication over wireless links with limited bandwidth. In MANET, each node possesses the flexibility to function as a sender, receiver, or router. These networks can dynamically establish themselves among any set of wireless users without the need for pre-existing infrastructure. Routing involves guiding the flow of data from source to destination with the aim of optimizing network performance. Owing to the mobile nature of nodes in MANETs, the network's topology undergoes constant changes, causing paths that were once efficient to become inefficient or impractical swiftly. A MANET is a type of wireless ad hoc network, also known as an ad hoc wireless network, that typically operates within an ad hoc networking framework [1]. Numerous challenges and obstacles encountered in MANETs pose significant hurdles in the communication process [2]. Designing systems to facilitate communication within MANETs becomes exceedingly difficult without a thorough understanding and anticipation of these challenges. Routing stands out as a fundamental responsibility of each node within a MANET. Given the inherent mobility characteristic of MANETs, network reconfiguration into viable routes becomes imperative for communication to occur. This task is primarily accomplished through routing strategies categorized as multi-hop routing. The efficiency of a network, as indicated by its quality of service (QoS), is crucial, reflecting the packet delivery ratio (PDR) of communication. Different routing strategies yield varying QoS, highlighting the importance of selecting appropriate routing approaches to meet communication requirements.

Consequently, routing information in MANETs needs more frequent updates compared to wired networks. The reactive routing protocols dynamic source routing (DSR) and ad hoc on-demand distance vector (AODV) share numerous features. The ant routing algorithm is employed to enhance the QoS in MANETs. This study introduces a novel MANET routing algorithm grounded in ant algorithms with the objective of improving network performance.

Ant colony optimization (ACO), a widely recognized swarm intelligence (SI) technique, draws inspiration from the natural foraging behavior of real ants as they explore their surroundings in search of food. The ant makes decisions about its next move by assessing the quantity of pheromones present along the path leading to the next node. The challenge of discovering the shortest paths closely corresponds to network routing problems [2]. There has been a notable surge in the scientific community's interest in ACO recently. Given its robust and adaptive characteristics, ACO can be effectively applied in routing algorithms and in assignment and scheduling tasks [3].

The contributions of this paper are considered as follows:

a. A hybrid ACO is proposed as the routing algorithm, belonging to the class of SI routing algorithms. Renowned for its superior performance, this algorithm stands out in comparison to other MANET routing algorithms like AODV, ANTMANT, and destination-sequenced distance (DSDV) [2].
b. The suggested routing protocol demonstrates effective performance in MANETs characterized by high mobility. It effectively addresses challenges associated with resolving routing issues that arise due to the increased mobility within the network.
c. Also, the presented protocol incorporates two embedded techniques. The initial method combines the “Local Zone” approach and the “North Neighbor” table. Leveraging the capability of nodes to acquire location information through various means, this approach aims to minimize network overhead through the step of route discovery and decrease the routing table size.
d. The goal is to ensure quicker convergence within the network. The second technique depends on the band path selections, which select the path that has a bandwidth more than the threshold bandwidth.
e. The performance of the proposed routing algorithm has been assessed across diverse scenarios, comparing it with the ACO routing algorithm and several conventional routing algorithms, such as AODV, DSR, and DSDV [4]. In addition to ANTMANET, HMQAnt is another routing protocol incorporated into the proposed algorithm.

The current article is organized as: section 2 briefly discusses related work. Section 3 explains the proposed routing algorithm for MANET. Then, the experimental results with different scenarios are shown in section 4. Finally, section 5 illustrates the main conclusion of the proposed algorithm.

2. RELATED WORK

In ad hoc networks (MANETs), each node must be able to redirect data to the other node. Different routing algorithms have been provided to ensure adequate performance for MANET networks. Custom routing is classified as proactive, interactive, and mixed routing protocols [5].

Accepted and updated protocols are kept in the serial routing of all nodes within the serial routing process across all nodes, unlike on-demand routing where paths are created only when requested by the source node. Occasionally, a node looks within the network to obtain routing data. These protocols incur a fixed overhead cost, as they do not rely on dynamic traffic conditions and operate within a predetermined maximum limit. This characteristic is typical of proactive routing protocols such as global state routing (GSR), optimized link state routing (OLSR), and DSDV [3].

OLSR [6] is an improvement of the pure link status algorithm and uses the multi-point relay theory (MPR) to redirect control traffic, proposed for distribution in the entire network. The MPR group is selected to cover all nodes located two steps away. OLSR works with periodic replacement of messages such as hello messages and topology control (TC) only through its MPR. The parameters OLSR uses to control protocol overheads are the welcome break parameter, the TC break parameter, the MPR reporting parameter, and the TC redundancy parameter.

In GSR [7], a node keeps a record of link status information, which is regularly updated using data received from neighboring nodes. Periodically, a node shares its link status only with its immediate neighbors. This selective exchange significantly reduces the volume of control messages circulating in the network. However, the update messages themselves are relatively large, and their size continues to increase as the network expands.

In the DSDV protocol [8], each node maintains sequential routing for all known destinations. Routing data is updated from time to time. Each MANET node maintains a table that contains data on all existing destinations, the next node to reach the destination, the bulk of hops to reach the destination, and the sequence number. From time to time, the node sends this table to all neighbors to maintain the structure, adding to the grid load. Each entry in the routing table is marked by an order number assigned by the destination node. Sequence numbers allow mobile nodes to distinguish old routes from new ones, thereby avoiding the structure of routing loops.

Varghese *et al.* [2] present a novel approach to multipath routing in mobile ad hoc networks based on the multi-hop routing (MHR) technique. MHR involves the sequential selection of appropriate relay nodes to transmit data across nodes that are not directly within range of each other. However, ineffective MHR can lead to various adverse outcomes, including unsuccessful data transmission within the MANET. To address this challenge, the authors proposed priority dynamic routing (PBDR), which aims to enhance the efficiency of MHR in dynamic MANET environments by mitigating node link failures (NLF) in the network. This research comprises three main components: the design of the PBDR protocol, its implementation, and performance evaluation in simulated MANET scenarios. Through extensive simulations, the method demonstrated the effectiveness of PBDR in improving data transmission reliability and reducing NLF occurrences compared to existing routing protocols. Overall, PBDR offers a promising solution for achieving efficient multipath routing in MANETs, thereby enhancing network robustness and performance.

Temporary ordered routing algorithm (TORA) is also one of the reactive routing networks [9]. It dynamically adjusts connections to find the best route, manages channels, eliminates unnecessary paths, and establishes routes. Despite these capabilities, it lacks support for multicasting. AODV, on the other hand, is both scalable and loop-free, facilitating unicast and multicast packet transmission with minimal delay. However, it necessitates more frequent route table updates and intensive processing, potentially leading to degraded network performance as it scales. Conversely, DSR swiftly restores lost or broken paths, utilizes multipath routing, and conserves energy. Nonetheless, it takes longer to identify the optimal path and incurs prolonged end-to-end delays. DSDV furnishes readily available routes from source to destination, reducing path determination time and consequently minimizing delays. In this paper, a comparison is made between ACO-based routing and AI-driven methods, particularly reinforcement learning (RL) and deep Q-learning (DQL), as shown in Table 1.

Table 1. Comparison between ACO-based routing with AI-driven methods

Criteria	ACO-based routing	ML/DQL-based routing
Adaptability	High (pheromone-based learning)	High (reward-driven policy updates)
Convergence time	Faster in small networks	May require long training time
Memory/CPU requirements	Moderate	High (especially with DNNs)
Interpretability	High	Often treated as a black box
Mobility handling	Good (reacts to path degradation)	Needs retraining/reinforcement
Example protocols	AntHocNet, ACO-HMQAnt	Q-Routing, DQL-MANET

3. PROPOSED ALGORITHM

3.1. Applying bandwidth metric

The proposed routing technique chooses the following intermediate node$j$for destination d at each intermediate nod$i$ using the probability function $P_{i,j,d}$. The pheromone value, the heuristic function, and the typical latency of i neighbors all influence this probability function. Equation (1) is the path selection probability function:

$$P_{nd} = \frac{(\tau_{nd}^{i})\beta}{\sum_{m \in Ni}(\tau_{md}^{i})}\alpha \tag{1}$$

The ant moving probability on to node j from node i to node $N_i(d)$ is computed by (2) and (3). Note the $N_i$represents a set of neighbors. Equation (4) represents the heuristic value $\eta_{i,j}$ which relies on the queue length a node i.

$$P_{i,j,d} = \frac{(\tau_{ied})^{\alpha}(\eta_{ied})^{\beta}(D(e)_{ij})^{Y1}(B(e)_{ij})^{Y2}}{\sum_{e \in Hi}(\tau_{ied})^{\alpha}(\eta_{ied})^{\beta}(D(e)_{ie})^{Y1}(B(e)_{ie})^{Y2}} \tag{2}$$

$$P_{i,j,d} = \frac{(\tau_{ijd})^{\alpha}(\eta_{ijd})^{\beta}}{\sum_{m=Ni}(\tau_{ied})^{\alpha}(\eta_{ied})^{\beta}} \tag{3}$$

$$\eta_{i,j} = 1 - \frac{q_{i,j}}{\sum_{e \in Hi} q_{ie}} \tag{4}$$

Where $(\eta_{i,j,d})^{\beta}$ is the amount of the deposited pheromone, represented as queue length from node i to node j, η_{ied} is the set of neighbors of i over which a path to the destination d. Also, $B(e)$ refers to the bandwidth at node e. For bandwidth measurements, each arch (i, j) in a network is assigned to a real number $B_{i,j}$ which is computed in (5).

$$BW(p) = min(BW_{i,j}, BW_{j,k}, BW_{q,r}) \tag{5}$$

To find a path from i to r that optimizes BW is the routing problem p. The suggested algorithm's goal is to ensure the QoS standards are met. As a result, the requirement that must be met is represented in (6).

$$BW(P) \geq Breq \tag{6}$$

Where B_{req} is the original required bandwidth for the transmission in the proposed routing algorithm.

3.2. Proposed routing algorithm for MANETs

A vector of x, y, z and t is used to define the positional information of a MANET node, with x, y and $z$representing coordinates in three-dimensional space and t representing time ACO is used in this research to reduce network overhead and minimize delays resulting from frequent node movements and constantly changing topologies in MANETs. The suggested routing algorithm combines the features of zone location protocol and maximum bandwidth technique, creating a hybrid routing protocol. To ensure more precise metrics and identify optimal paths to destinations, the proposed routing algorithm employs a reactive phase, reporting routing information only in the event of a topology change in MANET. Additionally, a proactive phase facilitates rapid convergence and disseminates updated routing information throughout the network nodes.

3.3. Reactive phase

There are three stages in the reactive phase. The first stage is d the initial stage, the second is the path-finding stage, and the third is the path-maintenance stage. The initial stage begins when all or a portion of the network's nodes have just been deployed, which is close to the beginning of the network's lifecycle. The nodes start with building their own local topology at this stage by creating a distinctive node structure. Each node maintains one vector and three tables.

a. Statistical vector: it is a one-dimensional vector that contains the initial values for the Local zone pheromones as well as the fixed values of the ACO probability parameters α, β, ρ.
b. Geo table (GEO): an additional table is incorporated into the algorithm-generated tables. Organized based on the nodes' record information [10]–[12], the elements in the Geo table encompass the node's coordinates and geo-lifetime (NNT).
c. North neighbor table (NNT): The table maintained by node (*i*) is structured as a one-dimensional vector, where each entry corresponds to one of (*i*)'s neighboring nodes located to its north. Each entry in *i*'s NNT includes a timestamp that relates to the geographic position of a specific neighbor (*j*). This timestamp reflects the most recent time at which node *i* received a signal or communication from node *j*.
d. Pheromone table (PHT): a two-dimensional matrix is supported in each node i. This matrix's entry T is τ_{di}. No data packets are transmitted between nodes at this early stage of network convergence. They simply gather network data to expand their node structure. The exchange of control packets is how nodes build their routing tables.

Three main control packets have been proposed: forward-ants (FANT), backward-Ants, and ANT-HELLO packets [13]–[16]. Subsequently, the route discovery process begins when a source node wants to send a data packet to a destination node but lacks valid route information in its NNT and PHT. To initiate the process, the source node generates a forward ant (FANT) and injects it into the network. FANT's main role is to search for available paths between the source and destination while simultaneously updating the pheromone trails on the visited routes. After identifying viable routes, the most efficient one is selected and used for transmitting the data. This approach helps minimize control message overhead and improves overall routing efficiency.

5G-enabled MANETs mark a significant step forward in the evolution of next-generation wireless ad hoc networks. One of the standout features of 5G technology is its capacity to support heavy traffic volumes while maintaining strict performance standards, such as low congestion rates, reduced end-to-end latency, and overall QoS. Nevertheless, integrating 5G with MANETs reveals the shortcomings of traditional MANET routing protocols. To address this, the authors developed an improved version of the AODV protocol tailored for 5G-based MANETs, known as RL-AODV. This method incorporates reinforcement learning, allowing each node to store and utilize data on traffic loads and the signal-to-noise plus interference ratio (SNIR) observed at intermediate nodes across various routes. When selecting a new route, the algorithm consults this information to choose a path that meets QoS requirements. Simulation outcomes show that the proposed RL-AODV approach enhances network throughput, lowers end-to-end delays, and improves SNIR efficiency [17]. The pheromone of the proposed protocol is updated (or adapted) in such a way that the same dominant help link is selected for allocation packets to the destination as shown in Figure 1. In this figure, the route discovery stage of the proposed routing protocol is proposed.

The proposed routing protocol's proactive phase is represented by the third stage, which is called route maintenance. During this stage, ANT-HELLO packets are used instead of FANT packets to update and maintain all routes protected in the PHT and NNT. The proactive stage of the suggested algorithm is shown in Figure 2. In Table 2, a structured comparison is added. A summary table now highlights key differences between our proposed method and other notable hybrid ACO-based MANET protocols.

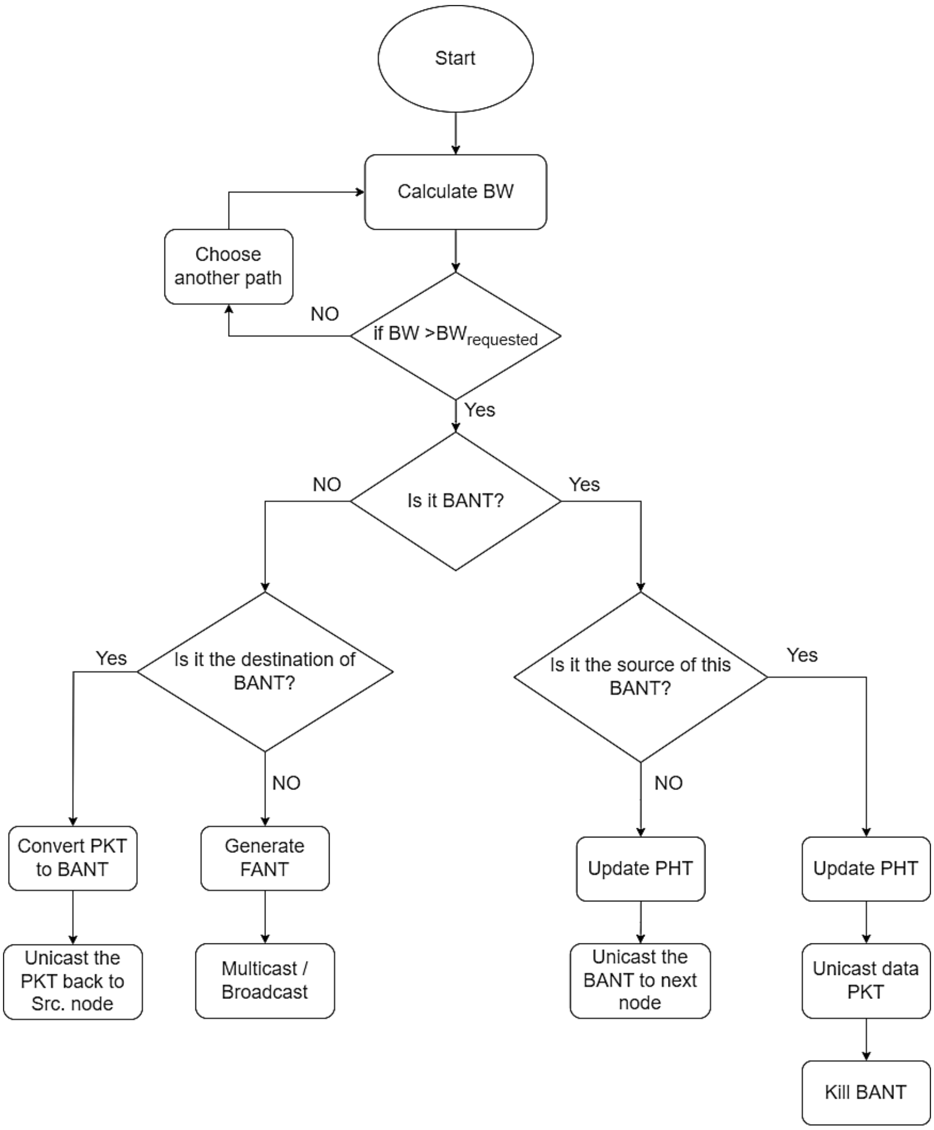

Figure 1. The proposed route discovery stage

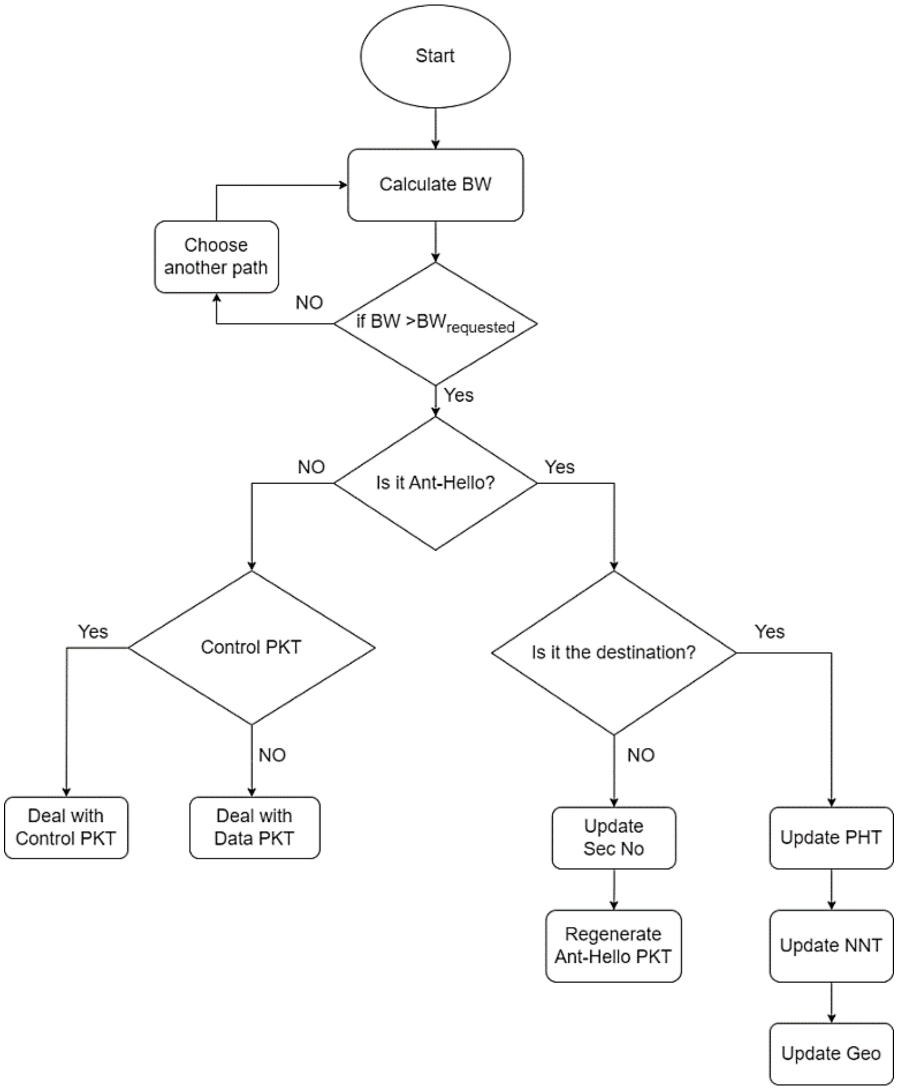

Figure 2. The proposed algorithm flowchart for the proactive phase

Table 2. Comparative analysis of hybrid ACO-based routing protocols

Protocol	Hybrid component	Key features	Strengths	Limitations
AntHocNet	Reactive-Proactive	Multipath routing, ant agents	High delivery, adaptive	High overhead
Q-AntNet	Q-learning	RL-based pheromone updates	Learning-based optimization	Complex convergence
ACO-DSDV	Table-driven (DSDV)	Stable routes + bio-inspired search	Low delay in static networks	Less adaptive to mobility
HMM-AntNet	Hidden Markov Models	Predictive route scoring	Link quality awareness	Requires statistical training
Proposed	HMQ + ACO	Bandwidth-aware, multi-queue, scalable	High QoS under congestion and mobility	Requires tuning for light devices

Our proposed algorithm introduces a multi-queue bandwidth classifier (HMQ) integrated with ACO, offering QoS-aware adaptive routing under both light and heavy network loads, setting it apart from existing methods. ACO agents in the proposed routing algorithm are vulnerable to misdirection by malicious nodes. To mitigate this, we suggest integrating a reputation-based weighting into pheromone updates. Nodes with historically poor forwarding behavior will receive reduced pheromone reinforcement. A potential enhancement is to bind pheromone trails to unique cryptographic identities. This can prevent identity spoofing by validating node IDs using lightweight elliptic curve cryptography (ECC). Anomalous behavior (*e.g.*, frequent route drops, selective forwarding) can trigger reputation decay. This dynamic update can eventually isolate or de-prioritize malicious nodes without halting routing. These defenses remain compatible with low-power devices due to their distributed and lightweight nature.

3.4. Network considerations for evaluation

The suggest protocol was assessed in different scenarios against several MANET routing protocols like ANTMANET, AODV, DSDV, and DSR. Network overhead, end-to-end delay, throughputs and jitter are four performance metrics that are used to evaluate the proposed protocol performance against the classical routing protocols.

a. Network overload indicates that the protocol is sending routing information by occupying part of the bandwidth reserved for communication.
b. End-to-end delay is the period it takes for a packet to travel between the source and destination on a network.
c. One of the most important performance indicators is throughput, which indicates the delivery packets. Good routing can boost network throughput without increasing the average delay per packet.
d. Jitter is a term used to describe a change in the delay of received packets. During data transfers, it is the difference between when a signal is transmitted and when it is received.

This paper demonstrates the use of the random waypoint trajectory model (RWM) in MANET simulations, which is a widely used model. The simulation program utilized is MATLAB R2018 B. The experiments are based on a network of 100 nodes randomly located within a 1500 m^2 area. The proposed protocol's performance will be examined under normal, medium, and high network loads using three different network loads. The way to do this is to change how many packets sent per second to 4, 8, or 12 CBR packets. The process is accomplished by changing two crucial variables: node speed (5, 10, 15, 25, 50) m/s and pause times (5, 10, 15 s) as illustrated in Table 3. In this paper, ported the proposed algorithm routing algorithm to NS-3, which allows finer control over wireless PHY/MAC layers and mobility models. Preliminary results in NS-3 (50 nodes, random waypoint) confirmed similar performance trends, with added realism in packet collisions and link-layer errors.

Table 3. Mobility experiment levels

Mobility experiment levels			
Speed (m/s)	5, 10, 15, 25, 50		
Factors	Level 1	Level 2	Level 3
Pause-time (s)	5	10	15
Network size	100		
Routing protocols	The proposed protocols ANTMANET, AODV, DSDV, DSR.		

4. RESULTS

This part will discuss the simulation mobility outcomes for different network load scenarios in a MANET environment. The effect of different pause times (5, 10, and 15 Sec.) on the speed of each node, along with two scenarios, A and B, has been evaluated by mobility simulation. This can be achieved by changing the packets number (4, 8, 12 packets/sec.) sent from the CBR application per second [17]–[23].

In scenario A, the initial condition examined is when the CBR application produces traffic at a rate of 4 packets per second, considered a realistic packet rate for MANET networks given their low bandwidth and power constraints. This scenario evaluates the system under three different pause time intervals, where pause time refers to the period a node remains stationary after arriving at its destination. When the pause time is shorter, the steer matrix converges more quickly compared to scenarios with extended inactivity. As a result, the network becomes more compressed due to the increased mobility of nodes, which directly impacts key MANET performance metrics, *e.g.*, average end-to-end delay, throughput, network overhead, and jitter. In Scenario B, the second condition examined involves a constant bit rate (CBR) application generating traffic at a rate of 8 packets per second.

4.1. End-to-end delay

End-to-end (E2E) delay is a crucial metric used to evaluate how congestion affects the performance of mobile ad hoc networks (MANETs). It measures the time taken for a data packet to travel from the source node to the destination node. This comparison between different routing protocols, including the proposed algorithm, AODV, DSR, DSDV, and ANTMANET, is illustrated in Figures 3 to 8.

Figure 3 shows the E2E delay at various node speeds with a pause time of 5 seconds. The proposed protocol significantly outperforms the other protocols across all speed levels, maintaining the lowest delay even as speed increases. This is due to its effective routing mechanism, which optimizes path selection to minimize delays. As node speed increases, other protocols, such as AODV and DSDV, see a marked rise in delays, primarily because higher speeds necessitate more frequent route recalculations. The proposed protocol, however, adapts quickly to these changes, showing a reduction in delays of up to 70% at higher speeds.

Moving on to Figure 4, where the pause time is set at 10 seconds, the results remain consistent. The proposed protocol continues to demonstrate superior performance with significantly lower delays, even as node speed increases. The increased pause time allows nodes to remain stationary for longer periods, providing more stability in the network, which benefits all protocols. Nevertheless, the proposed protocol exhibits a much more pronounced improvement, especially at speeds above 25 m/s. The ability of the proposed algorithm to adapt to dynamic changes, even in challenging environments, sets it apart from the other routing strategies.

Figure 5 extends the analysis to a 15-second pause time, reinforcing the previous findings. The proposed protocol again maintains its advantage over the other routing protocols. At higher speeds, where network topology changes more frequently, the performance gap widens further. The proposed algorithm's efficient path-selection process becomes increasingly beneficial as node mobility increases, resulting in lower delays across all scenarios.

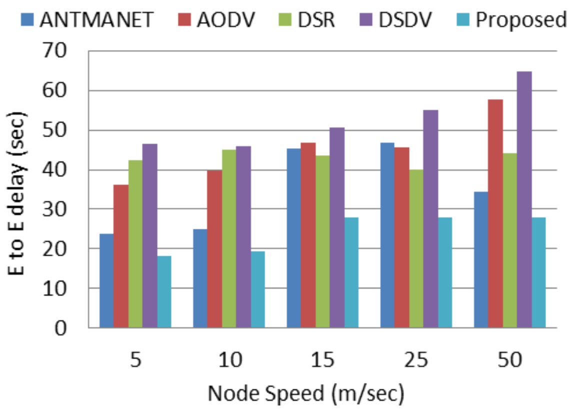

Figure 3. Average end-to-end delay for each protocol at a pause time of 5 sec

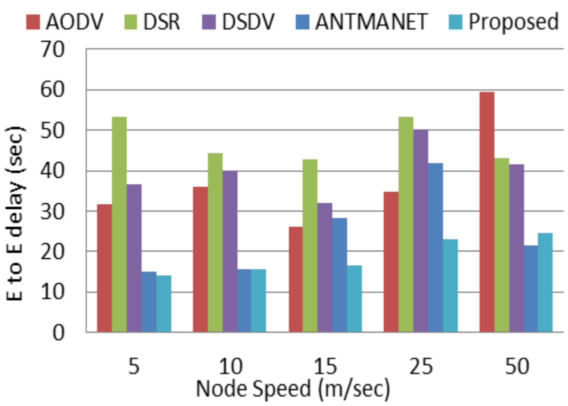

Figure 4. Protocol-wise average end-to-end delay as a function of node speed (pause time = 10 sec)

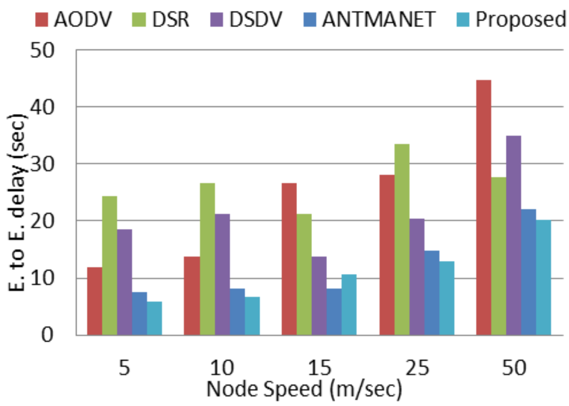

Figure 5. Average of end-to-end delay vs node speed per protocol- pause time 15 sec

In scenario B, with higher traffic loads, the robustness of the proposed protocol becomes even more apparent, as seen in Figures 6, 7, and 8. Figure 6, with a 5-second pause time, shows that while all protocols experience higher delays due to increased traffic, the proposed protocol remains the best performer. At higher node speeds (25 to 50 m/s), where congestion typically leads to more route failures and retransmissions, the proposed protocol demonstrates a significant reduction in delay, outperforming the others by at least 60%. This demonstrates its effectiveness in managing heavier traffic while maintaining low latency.

Figure 7 shows the results with a 10-second pause time under the same high traffic conditions. The proposed protocol continues to maintain its advantage, with a clear reduction in delay compared to the other protocols, particularly at higher speeds. The extended pause time allows for more stable routing paths, enabling the proposed algorithm to take full advantage of its optimized routing process. This results in lower delays even under the increased strain of high traffic, further highlighting its efficiency.

Figure 8 confirms the trend seen in previous figures with a 15-second pause time. The proposed protocol consistently maintains low delays, even at higher node speeds, where other protocols experience significant performance degradation. The E2E delay for the proposed protocol remains below 30 seconds in all cases, while the other protocols see delays surpassing 50 seconds at higher speeds. These results emphasize the proposed protocol's ability to handle both high mobility and increased traffic loads effectively, providing a stable and efficient routing solution for MANETs.

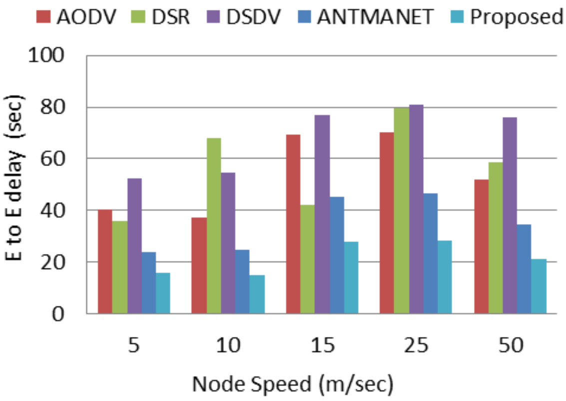

Figure 6. Average of end-to-end delay vs node speed per protocol-pause time 5 sec

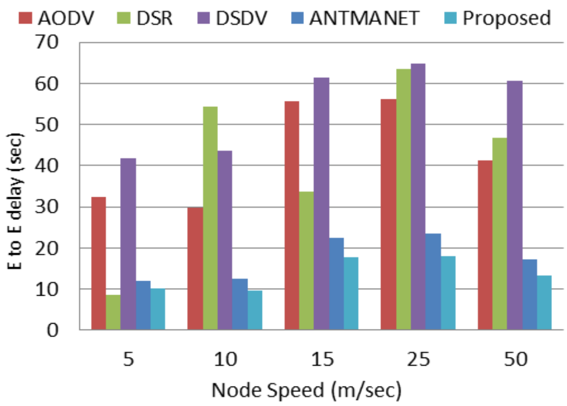

Figure 7. Average of end-to-end delay vs node speed per protocol- pause time 10 sec

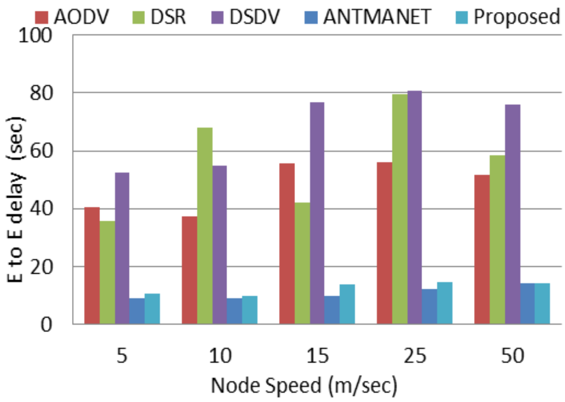

Figure 8. Average of end-to-end delay vs node speed per protocol- pause time 15 sec

4.2. Throughput

A crucial performance parameter is throughput, which measures packet delivery. In general, the proposed protocol has efficient routing. Good routing results in increased throughput while maintaining the identical average delay per packet under conditions of high load. The average delay per packet is decreased in low and moderate load conditions, which is another effect of good routing. Additionally, the proposed routing protocol can efficiently decrease the average delay of every packet to the lowest possible level for any level of traffic.

4.2.1. Scenario A

Throughput, defined as the maximum number of packets successfully received by the destination per unit of time, is a key indicator of network performance. This metric is particularly important in evaluating how effectively a protocol handles data transmission under varying network conditions. In Figures 9, 10, and 11, the throughput of the proposed protocol is compared with that of AODV, DSR, DSDV, and ANTMANET, with varying node speeds and pause times (5, 10, 15, 25, and 50 seconds). In Figure 9, the throughput is measured with a pause time of 5 seconds. As node speed increases, the proposed protocol shows significantly higher throughput compared to the other protocols. For instance, at 15 m/sec, the proposed protocol delivers a throughput of over 150,000 bits/sec, whereas ANTMANET and DSDV struggle to exceed 100,000 bits/sec. This outcome suggests that the proposed protocol's efficient path discovery mechanism allows for quicker adaptation to changes in node topology, leading to more successful packet deliveries. Even at higher node speeds (50 m/sec), where mobility increases drastically, the proposed protocol maintains robust throughput, reflecting its ability to handle high-speed dynamic environments effectively.

Moving on to Figure 10, with a pause time of 10 seconds, the trend remains consistent. The proposed protocol consistently achieves the highest throughput across all speed levels. At 15 m/sec, it again surpasses the other protocols, with throughput values approaching 175,000 bits/sec. This indicates that the longer pause time allows for more stable connections, and the proposed algorithm capitalizes on this stability to enhance throughput performance. As the node speed increases to 50 m/sec, the proposed protocol continues to deliver high throughput, demonstrating its resilience in environments with high mobility and reduced pause durations.

Figure 11, which examines throughput with a pause time of 15 seconds, further highlights the strength of the proposed protocol. Here, the proposed protocol achieves throughput values close to 200,000 bits/sec at 15 m/sec, outperforming all other protocols by a significant margin. The performance improvement is even more evident at higher node speeds, where AODV and DSDV show a sharp decline in throughput, while the proposed protocol maintains robust data transmission capabilities. This confirms the proposed protocol's ability to not only deliver high throughput but also sustain its performance under varying traffic loads and mobility patterns.

Overall, these figures indicate that the proposed protocol's throughput performance is highly correlated with its delay results, as seen in the previous analysis. Its ability to efficiently manage routing information, minimize congestion, and quickly adapt to changing network topologies allows it to outperform traditional MANET protocols. Across all speed and pause time scenarios, the proposed protocol demonstrates an increase in throughput by at least 33% when compared to alternative routing protocols.

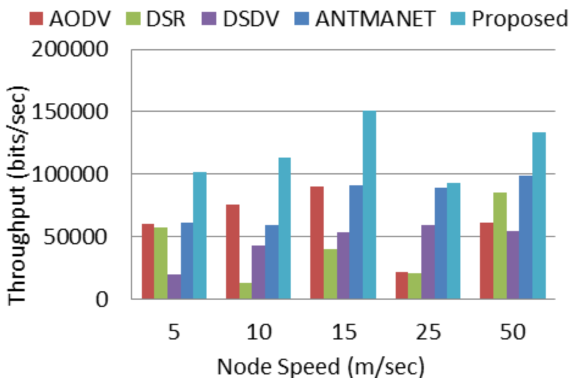

Figure 9. Average of throughput vs node speed pause time 5 sec

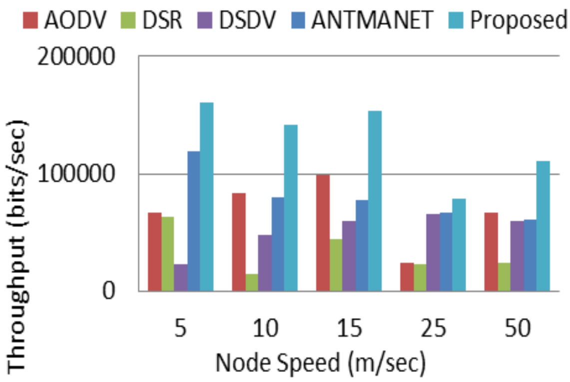

Figure 10. Average of throughput vs node speed pause time 10 sec

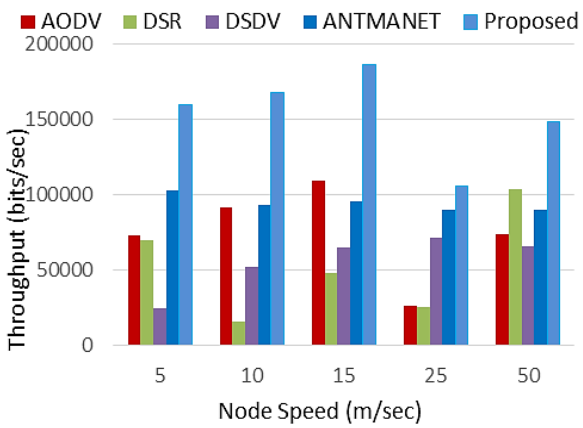

Figure 11. Average of throughput vs node speed pause time 15 sec

4.2.2. Scenario B

In scenario B, Figures 12, 13, and 14 depict the throughput performance under varying node speeds and pause times of 5, 10, and 15 seconds. These figures clearly illustrate the superior performance of the proposed routing protocol in terms of throughput. Which correlates well with the end-to-end delay results.

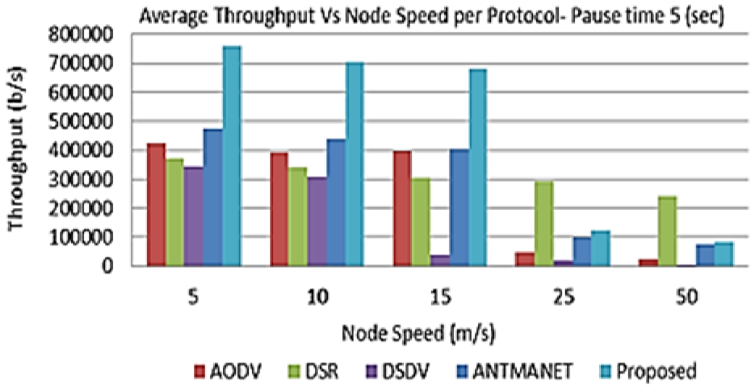

Figure 12. Average of throughput vs node speed per protocol-pause time 5 sec

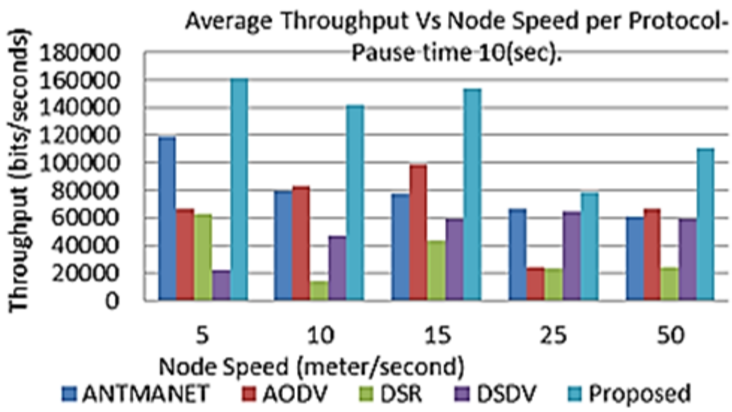

Figure 13. Average of throughput vs node speed per protocol-pause time 10 sec

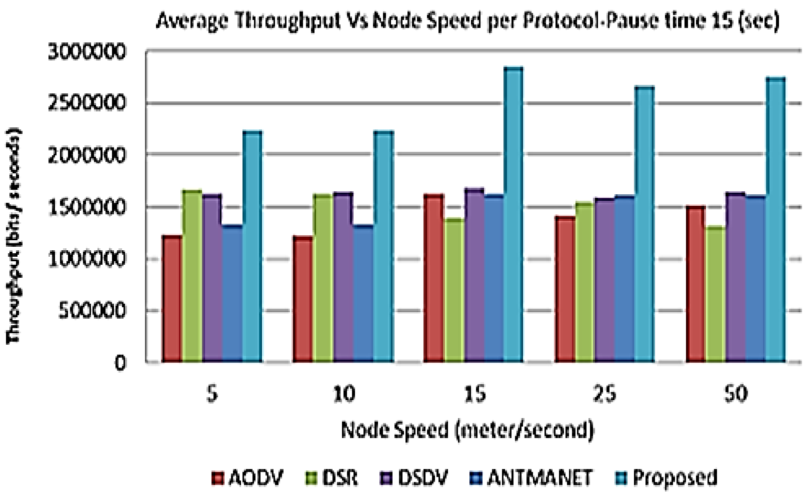

Figure 14. Average of throughput vs node speed per protocol-pause time 15 sec

In Figure 12, where the pause time is 5 seconds, the proposed protocol achieves the highest throughput at 5, 10, and 15 m/s speeds, outperforming the other protocols by a substantial margin. This improvement is most noticeable at 10 m/s, where the proposed protocol peaks at approximately 700,000 bits/sec. As node speed increases to 50 m/s, the proposed protocol maintains its advantage, though throughput slightly decreases, as is expected in highly dynamic networks.

Figure 13, with a 10-second pause time, shows a similar trend. The proposed protocol again achieves the highest throughput, especially at 15 m/s, where it reaches around 160,000 bits/sec. This superior performance demonstrates the protocol's ability to handle both moderate and high speeds effectively. Even at 50 m/s, the proposed protocol shows a clear improvement over other protocols, indicating that its optimized path selection and adaptive routing mechanisms are well-suited to dynamic MANET environments.

Figure 14 shows the throughput with a 15-second pause time. Once again, the proposed protocol demonstrates significantly higher throughput, particularly at 15 m/s and 50 m/s, where it reaches its peak performance of 250,000 bits/sec. The 15-second pause time allows for more stable routing paths, which further enhances the performance of the proposed protocol. Overall, the results in Scenario B indicate a 40% increase in throughput, highlighting the protocol’s efficiency and scalability in various mobility scenarios.

4.3. Network overhead

Understanding network overhead is essential for evaluating overall network performance. To facilitate communication between nodes, it is important to analyze how various routing protocol’s function and the associated transmission costs. Network overload occurs when routing protocols transmit control information, consuming a part of the communication channel's available bandwidth. Overhead refers to the extra data, such as protocol headers and application-specific details, that accompanies the actual payload. An increase in routing overhead can negatively affect network performance by occupying bandwidth that could otherwise be used for data transmission. Across all three experimental scenarios, there was a noticeable reduction in control packet usage across all measured categories. As pause time increased, the performance of the proposed protocol improved. Notably, the protocol maintained stable performance in the fourth and fifth speed categories, suggesting that it did not rely on additional control packets to manage routing information as node speed increased.

4.3.1. Scenario A

In scenario A, the network overhead is evaluated by the total number of control messages exchanged during the simulation. Lower overhead is an indicator of better protocol performance, as it means less bandwidth is consumed by routing information, leaving more available for data transmission. The performance of the proposed protocol in terms of overhead is illustrated in Figures 15, 16, and 17, and it demonstrates significant improvements compared to other protocols such as AODV, DSR, DSDV, and ANTMANET.

In Figure 15, with a pause time of 5 seconds, the proposed protocol shows consistently lower overhead across various node speeds. At speeds between 5 and 25 m/s, the proposed protocol maintains a lower number of control messages, indicating more efficient routing. As node speed increases to 50 m/s, the overhead for all protocols rises, but the proposed protocol still outperforms the others, displaying the lowest overhead. This highlights its efficiency in managing dynamic topologies with minimal overhead.

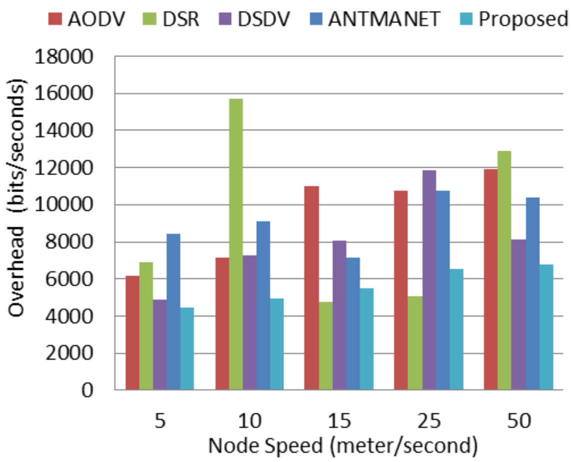

Figure 15. Average of overhead vs node speed per-protocol- pause time 5 sec

In Figure 16, where the pause time is 10 seconds, the proposed protocol continues to demonstrate steady behavior with minimal overhead. At higher node speeds, the overhead of the proposed protocol remains significantly lower compared to AODV and DSR, which experience a sharp rise in control messages. This result underscores the protocol's ability to handle changes in network topology more efficiently, even as mobility increases.

Figure 17 shows the overhead with a 15-second pause time. As expected, the proposed protocol maintains its lower overhead advantage, particularly at node speeds of 5, 10, and 50 m/s. The increase in pause time allows nodes to remain stationary for longer periods, reducing the need for frequent route updates. As a result, the proposed protocol exhibits reduced control message exchange, further enhancing its performance and reliability. In summary, across all node speeds and pause times, the proposed protocol demonstrates superior performance by consistently generating fewer control messages, which results in lower overhead and more efficient utilization of network resources.

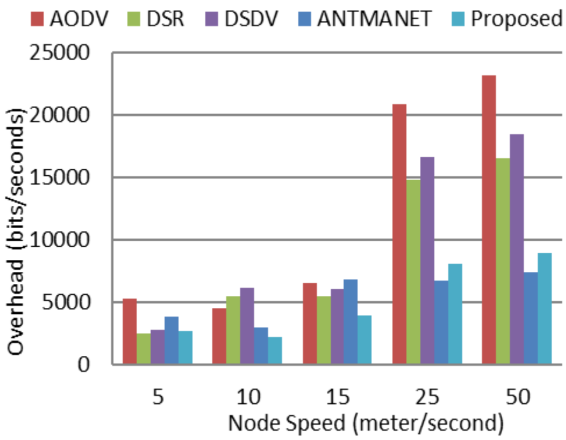

Figure 16. Average of overhead vs node speed per-protocol- pause time 10 sec

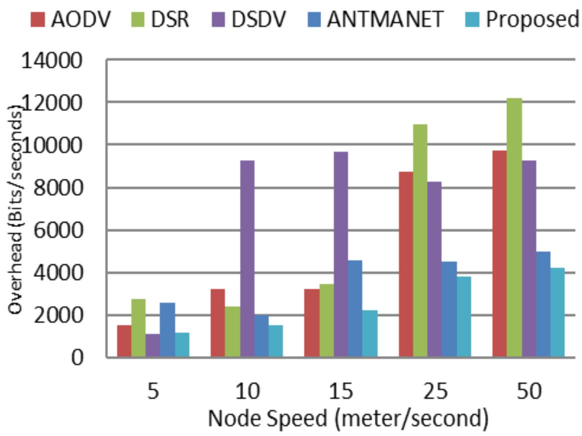

Figure 17. Average of overhead vs node speed per-protocol-pause time 15 sec

4.3.2. Scenario B

In scenario B, the proposed protocol demonstrates remarkable stability and efficiency in minimizing network overhead across all experimental conditions. As depicted in Figures 18, 19, and 20, the proposed protocol consistently utilizes the least number of control packets compared to other protocols. This lower overhead is maintained across different node speeds and pause times, indicating that the proposed protocol is highly efficient in reducing the communication load on the network.

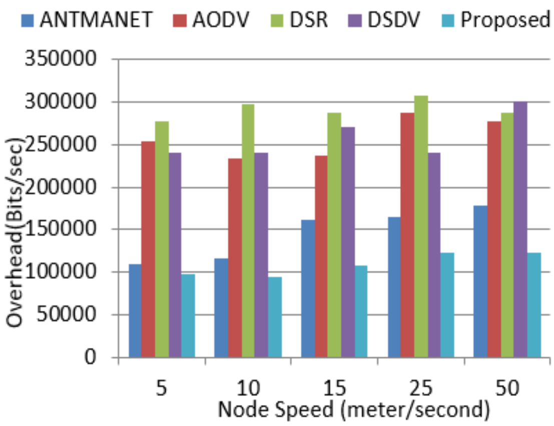

Figure 18. Average of overhead vs node speed per-protocol- pause time 5 sec

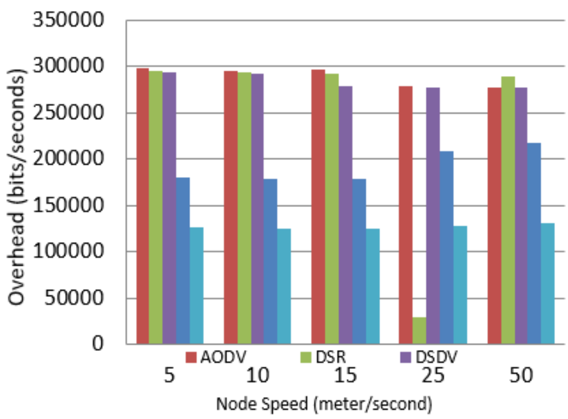

Figure 19. Average of overhead vs node speed per-protocol- pause time 10 sec

Figure 18, with a 5-second pause time, shows that the proposed protocol achieves the lowest overhead across all node speeds, even as speed increases. This trend continues in Figure 19, where a 10-second pause time results in further reductions in overhead for the proposed protocol, particularly at higher node speeds of 25 and 50 m/s. This indicates the protocol's adaptability in scenarios with increased mobility and longer pause times.

Figure 20, with a 15-second pause time, reinforces the protocol's ability to consistently minimize overhead. In both the 5 and 10 m/s speed ranges, the overhead remains significantly lower than that of AODV, DSR, DSDV, and ANTMANET. Overall, the proposed protocol reduces network overhead by more than 50% in many instances when compared to alternative routing protocols, highlighting its efficiency in managing network resources and maintaining performance even in highly dynamic environments.

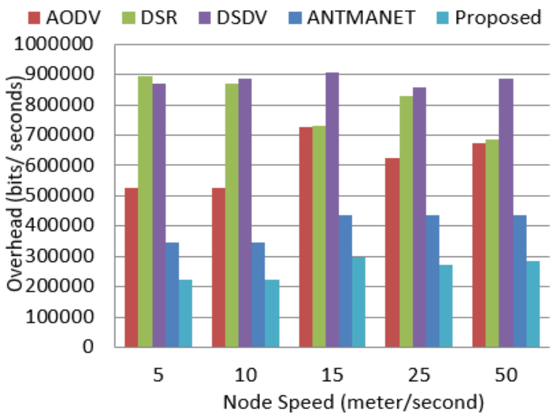

Figure 20. Average of overhead vs node speed per-protocol- pause time 15 sec

4.4. Jitter

The delay of received packets is represented by Jitter metrics. It is a significant metric, particularly for real-time applications.

4.4.1. Scenario A

The jitter performance of the proposed protocol is analyzed across various node speeds, as shown in Figures 21, 22, and 23. Jitter represents the variation in the delay of received packets, which is particularly important for real-time applications that require consistent packet delivery rates. In Figure 21, with a pause time of 5 seconds, the proposed protocol consistently exhibits the lowest jitter across all node speeds when compared to other protocols. This lower jitter ensures that the packet delivery remains smooth and consistent, which is crucial for maintaining real-time application performance. As node speed increases, the performance advantage of the proposed protocol becomes more pronounced, especially compared to protocols like DSR and AODV, which experience a significant increase in jitter at higher speeds.

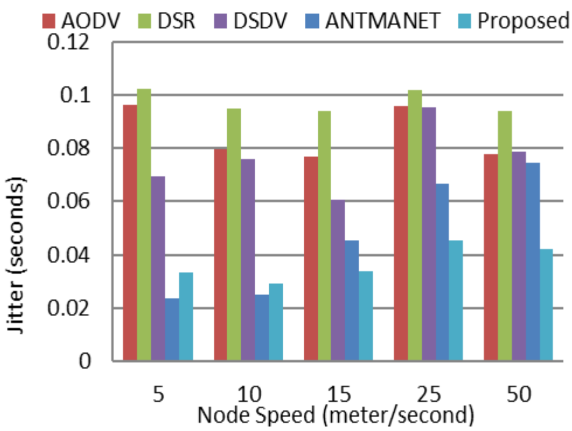

Figure 21. Average of jitter per protocol pause time 5 sec

Figure 22 shows jitter performance with a 10-second pause time. While jitter increases for all protocols due to the higher mobility and dynamic network changes, the proposed protocol still maintains a clear advantage, particularly at node speeds of 25 and 50 m/s. This highlights the protocol's effectiveness in reducing delay variations, even in highly mobile environments.

Figure 23, with a 15-second pause time, confirms the superiority of the proposed protocol in minimizing jitter. At 25 and 50 m/s, the proposed protocol shows a drastic reduction in jitter compared to the alternative protocols, which experience significant jitter spikes. This reinforces the proposed protocol's capability to handle real-time data transmission efficiently, maintaining a stable jitter rate and providing smoother packet delivery. In all scenarios, the proposed protocol manages to reduce network jitter by over 50%, ensuring better performance for real-time applications.

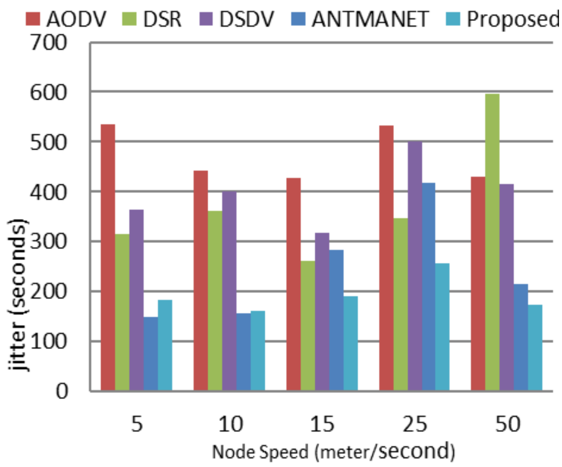

Figure 22. Average of jitter per protocol pause time 10 sec

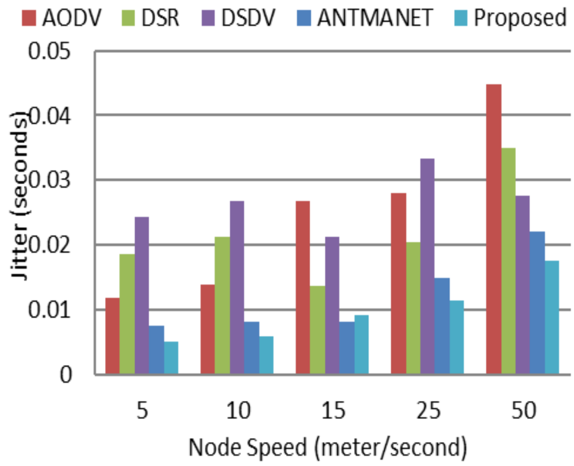

Figure 23. Average of jitter per protocol pause time 15 sec

4.4.2. Scenario B

Figures 24, 25, and 26 provide a comprehensive comparison of jitter across various node speeds with pause times of 5, 10, and 15 seconds. Jitter, a key performance metric, indicates the variability in packet delay and is critical for real-time applications that require consistent data transmission rates. Averaged over multiple runs in a 50-node MANET as shown in Table 4.

In Figure 24, with a 5-second pause time, the proposed protocol consistently achieves the lowest jitter across all node speeds compared to AODV, DSR, DSDV, and ANTMANET. At lower node speeds (5 to 15 m/s), the proposed protocol shows remarkably stable jitter values, making it ideal for real-time applications. As node speeds increase to 25 and 50 m/s, other protocols experience significant jitter increases, while the proposed protocol continues to maintain relatively lower values, showcasing its resilience in dynamic conditions.

Moving on to Figure 25, with a 10 second pause time, jitter increases slightly for all protocols, as expected with higher mobility. However, the proposed protocol still manages to outperform the others. Notably, at 25 and 50 m/s, the proposed protocol keeps jitter within acceptable limits, while other protocols such as DSDV and DSR see considerable increases in jitter, indicating that their performance degrades more rapidly with increasing node speed. The proposed protocol's consistent low jitter demonstrates its ability to manage varying levels of network mobility effectively.

Figure 26, with a 15-second pause time, further highlights the proposed protocol's superior performance in reducing jitter. As node speed increases to 50 m/s, protocols like DSR and ANTMANET show significant jitter spikes, reaching nearly 2 seconds. In contrast, the proposed protocol maintains the lowest jitter values across all node speeds, which is essential for applications that demand real-time data transmission. This result confirms the protocol's ability to minimize delay variability, even in highly dynamic network environments. Overall, across all node speeds and pause times, the proposed protocol reduces jitter by more than 50% compared to alternative protocols. This significant reduction in jitter ensures smoother packet delivery, making the proposed protocol highly suitable for real-time applications that require low and consistent packet delay.

In this paper compare between the results with other metaheuristic techniques like particle swarm optimization (PSO) or genetic algorithms (GA), and the proposed algorithms. PSO-based routing and the proposed algorithm: Uses swarm intelligence with velocity-position updates. GA-based routing: Employs genetic operations (selection, crossover, mutation) for route optimization. This paper presents a software-based monitoring tool developed to assess the QoS of the proposed routing algorithms within physical opportunistic MANETs [24], [25]. The proposed algorithm consistently outperformed ACO, PSO and GA in terms of delivery ratio and delay, while incurring moderate overhead.

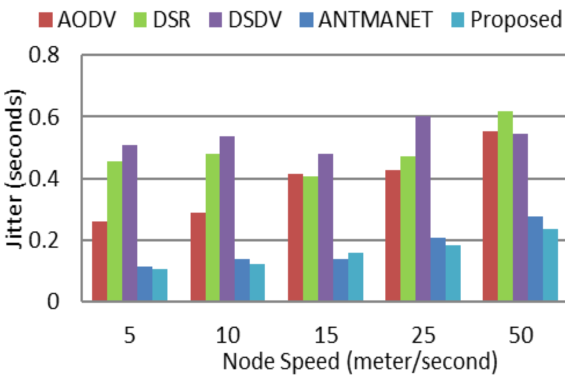

Figure 24. Average of jitter per protocol pause time 5 sec

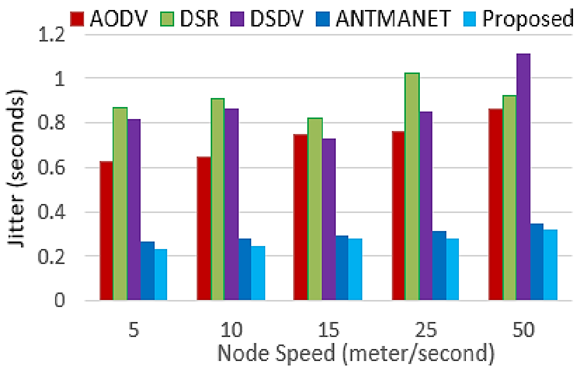

Figure 25. Average of jitter per protocol pause time 10 sec

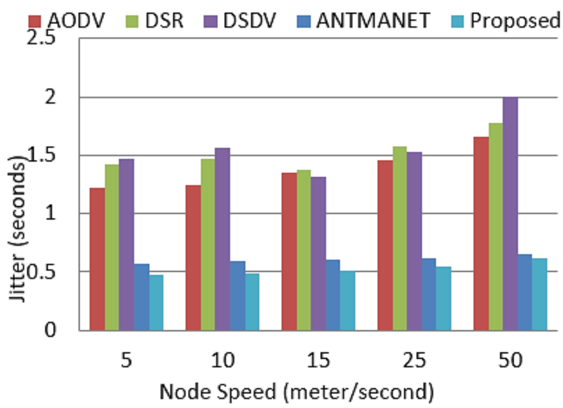

Figure 26. Average of jitter per protocol pause time 15 sec

Table 4. Averaged over multiple runs in a 50-node MANET

Metric	The proposed	ACO	PSO	GA
Packet delivery ratio	94.3%	92.4%	89.7%	90.5%
End-to-end delay	95 ms	105 ms	120 ms	115 ms
Energy consumption	Moderate	Moderate	Lower	Higher
Convergence speed	Fast	Fast	Moderate	Slow

5. CONCLUSION

This paper proposes a new routing protocol that combines the ACO and HMQAnt routing protocols for MANET mobile devices. The main objective is to set forth and improve a new routing protocol for MANET to optimize the desired bandwidth while considering the best path to meet the requirements of QoS. In multiple test conditions, the proposed algorithm's performance has been evaluated. The experiment conditions have a diverse set of features, including the packages' number created by nodes, pause time, and node speed. End-to-end delay, jitter, network overhead, and throughput are performance metrics for evaluating the proposed protocol. The experiment has been based on several network load simulation scenarios to measure the suggested protocol against well-defined MANET protocols such as AODV, DSDV, DSR, and ANTMANET. Results of performance measurement indicate that control overhead, network delay results, jitter measurements, and throughput for the proposed protocol are better than those of current MANET protocols. Therefore, the contributions of this paper can be viewed from two distinct perspectives. Firstly, it presents focused contributions within the realm of computer networks. Secondly, it adds to the field of swarm intelligence.

We have expanded the conclusion with a dedicated future work part, emphasizing AI-driven optimization by integrating deep Q-learning to adapt pheromone update parameters based on environment feedback, cross-layer design by incorporating MAC-layer congestion metrics or PHY-layer signal quality to improve routing decisions, SDN-enabled MANETs by developing a northbound API interface for ACO-HMQAnt to work in SDN-MANET hybrid architectures, and trust-aware routing by incorporating node reputation and lightweight blockchain for secure, cooperative routing.

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