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RESEARCH ARTICLE

Multipath Relay (MPR) Node Selection for Collision Avoidance and Efficient Routing in Mobile Ad Hoc Network

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Abstract

Mobile Ad Hoc Network (MANET) are characterized by dynamic topologies, limited bandwidth, and the absence of centralized control, making reliable data transmission a significant challenge. The performance of the network is frequently deteriorated by collisions are concurrent transmissions and ineffective relay node selection. This research suggests a new method for choosing multipath relay nodes that minimises packet collisions and improves MANET overall routing efficiency. OS approach ensures optimal route diversity and low interference by dynamically assessing possible relay nodes using a composite measure that takes into account node mobility, residual energy, and link stability. The technique was compared to existing Multi Path Relay (MPR) selection algorithms through simulations using NS3. The experimental findings show that, under different network densities and mobility models, there is a significant decrease in end-to-end delay, an improvement in packet delivery ratio, and a greater throughput. These enhancements validate that the strategy is successful in preserving reliable and effective communication channels. The results possess significant implication for mission-critical and delay-sensitive MANET applications, including military communications and disaster recovery.

Keywords: Ad Hoc Network (MANET), Multipath relay (MPR), Collision Avoidance, Efficient Routing, Packet Delivery Ratio (PDR), Throughput, End-to-End delay.

Introduction

MANET is made up of mobile nodes that do not depend on any permanent infrastructure and connect with each other over wireless communications. As depicted in Figure 1, every network node has the ability to function as a host and a router, sending data to other nodes to guarantee end-to-end connection (Roy, 2020). MANET's self-configuring and infrastructure-less design provides numerous advantages, particularly in urgent or mission-critical scenarios.For instance, MANET can be quickly implemented to facilitate coordination among emergency responders in followings of a natural disaster, where communication infrastructure may be severely damaged or destroyed. Similarly, MANET enables tactical communications by establishing a resilient and adaptable communication network on the spot, which is crucial in military operations where mobility and rapid deployment are crucial. They also provide a cost-effective way to provide network access in underdeveloped locations without conventional broadband connectivity (Finabel, 2022).

The inherent difficulties presented by the decentralised structure of mobile Ad Hoc Networks, dynamic topologies, limited energy resources, and unstable wireless links have made routing a major area of study. MANETs differ from conventional wireless networks because these characteristics require specialized routing protocols that

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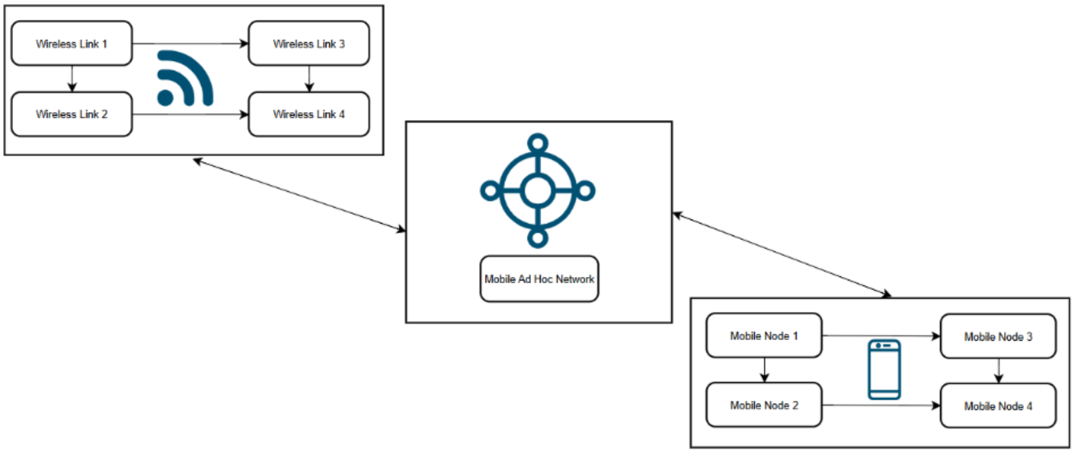

Figure 1: Architecture of a Mobile Ad Hoc Network (MANET)

can quickly adapt to frequent topology changes (Roy et al., 2020; Zhang et al., 2023).

Multipath relay node selection (MPR) has emerged as an essential method for guaranteeing robustness, fault tolerance, and load balancing in such dynamic environment settings. Multipath routing improves throughput and reliability by enabling data to travel over several separate routes from its source to its destination. Conventional MPR-based techniques frequently perform poorly in situations with high mobility or network congestion. These circumstances may result in longer delays, more packet collisions, and inadequate route choices. These difficulties highlight the need for more sophisticated and flexible methods of relay node selection. These methods must to be able to evaluate the network's present condition and make prudent choices about which nodes ought to serve as relays (Zhang, 2023).

MANETs provide a distinct set of technological hurdles due to their dynamic and decentralised nature, despite their significant advantages. The frequent and inconsistent changes in network architecture brought on by node mobility are one of the main problems. The rapid movement of nodes into and out of communication range might result in broken links and the requirement for continuous route changes. It might be challenging to establish steady and dependable communication pathways due to route irregularities brought on by these frequent topological changes. Furthermore, it is challenging to effectively manage network resources and coordinate transmissions in MANETs due to the absence of centralised control. Among these, the twin goals of minimizing packet collisions and enhancing routing efficiency remain crucial.

Literature Review

Rosati et al. (2013) proposed the Predictive Optimised Link State Routing protocol (OLSR) and MPR-based strategies have shown effectiveness in moderately stable network conditions, their performance often degrades under scenarios involving high mobility or dense node deployments. The degradation in mobile aware routing algorithm primarily stems from static or suboptimal relay node selection processes that do not adapt well to fluctuating network conditions (Sirmollo, 2021).

Paraskevas et al. (2016) proposed a multi-metric energy-efficient routing method for MANETs. Robinson and Rajaram (2015) introduced an energy-aware multipath routing scheme based on Particle Swarm Optimization.

Sivaranjani et al. (2024) developed a trust-optimized node selection method using the Eigen Neighbor Rank Trust Algorithm. S. Sarkar and R. Datta (2017) proposed a mobility-aware route selection technique for MANETs where mobility-aware schemes prioritize nodes with lower relative mobility, under the assumption that slower-moving nodes are more likely to maintain consistent links over time.

Singh and Dutta (2011) introduced temporal modeling of link characteristics in MANETs that can reduce route breakages and re-routing frequency but may overlook energy constraints or current link quality, leading to imbalanced node usage or poor performance under varying signal conditions. Chowdhuri et al. (2018) developed a relay node selection algorithm with minimum power consumption for MIMO-integrated MANETs and this trade-off highlights the limitations of single-metric strategiesin dynamic MANET environments.

A study proposed by Francis Antony Selvi and Manikandan (2017) in Ant based multipath backbone routing for load balancing in MANET has combined signal strength and link stability to create a more comprehensive view of node suitability for relay tasks. However, there is a limitation due to single metric usage .

S. Kaviani et al. (2023) proposed Deep MPR using Enhancing Opportunistic Routing in Wireless Network through Multi-Agent Deep Reinforcement Learning method have enhanced security and reliability, and often increase computational and memory overhead, making them less practical for real-time applications or resource-constrained nodes. Fault-tolerant multipath routing scheme for energy efficient wireless sensor Network introduced by P. Chanak et al. (2013) and Multipath source routing strategies for video transmission in ad hoc wireless Network developed by M. A. Santos et al. (2015) has gained popularity as a means to improve load balancing, reduce latency, and increase fault tolerance in MANET.

Zhou et al. (2016) initiated one of the earliest structured approaches by developing an interference-aware multipath routing protocol, This protocol evaluated link quality to prevent overlapping paths and reduce inter-path interference. While effective, it required extensive link-state information, increasing overhead. Fang and Lin (2017) introduced a channel-aware scheme leveraging spatial diversity to select paths based on channel conditions. Collision in MANET often arises from simultaneous transmissions over shared channels was addressed here. This reduced collision but introduced complexity in maintaining channel state information.

Choi et al. (2018) proposed a relay selection method integrated with contention window tuning, dynamically adjusting backoff intervals based on node density at the MAC layer. This enhanced channel access efficiency but required accurate local density estimation. Wu et al.,2020 presented a reinforcement learning-based protocol that learns optimal relay nodes by interacting with the network environment. Recent trends have embraced artificial intelligence for decision-making under uncertainty. It successfully adapted to mobility and density variations but incurred a training overhead and slower initial convergence.

Liu and Peng (2021) proposed a cross-layer framework where routing decisions were jointly influenced by MAC and physical layer parameters. By combining residual energy, link quality, and buffer occupancy, this method achieved lower collision rates and improved delivery ratios. Rao et al. (2016) introduced a stability-based metric for relay node selection. Route stability is central to sustaining end-to-end connectivity in high-mobility environments. Nodes with lower mobility variance and higher historical stability were favoured. However, its responsiveness in highly dynamic environments was limited.

Ahmed et al. (2019) enhanced this by integrating load balancing with stability, reducing route breaks and congestion. They employed a utility function considering buffer status and queue length. Li and Kumar (2018) proposed a geographic multipath routing protocol selecting relay nodes based on location proximity and directionality. With the growing availability of GPS and localization systems, geographic routing has become viable. Although efficient in open terrains, its performance degraded in urban or obstacle-rich areas. Singh et al. (2020) proposed a mobility-aware clustering technique where cluster heads coordinated multipath discovery. Clustering enhances scalability and coordination. This method improves route stability and minimized redundant transmissions, though cluster maintenance overhead remained a concern.

Kang and Zhao (2021) developed an opportunistic protocol using hierarchical clusters. Relay nodes were chosen based on historical cooperation scores and availability, ensuring adaptability to frequent topology changes. Jin et al. (2018) conducted extensive simulations to compare various relay selection strategies under mobility and traffic patterns. Their study emphasized that while centralized algorithms offered better route quality, distributed schemes outperformed them in delay and scalability.

Proactive protocols like the Optimized Link State Routing (OLSR) protocol maintain routes to every node continuously. However, this comes at the expense of higher overhead because of the continuous route updates. The MPR idea which was introduced by OLSR, reduces duplicate transmissions by assigning specific nodes the task of forwarding broadcast messages. Static metrics like the number of neighbours or hop count are commonly used in OLSR for MPR selection, but it fails to accurately represent real-time network characteristics such node mobility, energy availability, or connection quality. Consequently, in highly dynamic or crowded network situations, the chosen MPR might not be the most reliable nodes for data forwarding (Arafat and Moh, 2017).

This paper suggests a novel multipath relay node selection method that incorporates three crucial metrics node mobility, residual energy, and link stability in order to address these issues. The suggested approach aims at finding a compromise between energy efficiency, link robustness and route reliability when assessing relay candidates using this composite score. Furthermore, redundancy and fault tolerance are enhanced by the use of multipath routing. In order to avoid the need for instant route rediscovery in the event of a path failure, several disjoint or partially overlapping pathways are built between the source and destination nodes.

Objectives

- 1. To provide an efficientMPR node selection method that reduces packet collisions and improves routing efficiency.
- To simulate and assess the suggested method's performance in relation to existing MPR selection techniques.
- To verify the efficacy of the approach in enhancing network performance and to monitor the performance metrics like throughput, packet delivery ratio, and end-to-end latency.

- To enable intelligent relay node selection that is adapted to the dynamic character of MANET settings in order to guarantee the increased route variety and less interference.

Methodology

Traditional MPR-based protocols, such as OLSR, use static topological data to pick certain nodes as multipoint relays in an effort to decrease duplicate retransmissions. However, these protocols do not take into account real-time considerations like traffic dynamics, channel interference, or adaptive routing requirements. These protocols frequently communicate over a single channel, lack load balancing, and have poor performance in dense or highly mobile networks because of inefficient spectrum use and unmanaged collisions. Critical relay nodes degrade more quickly as a result of their disregard for energy optimisation. Reactive protocols, such as DSR and AODV, on the other hand, create routes only when necessary. AODV, which performs well in highly mobile situations but suffers from higher control traffic and discovery delays, employs RREQ and RREP messages for dynamic route discovery and maintenance. DSR effectively manages topology changes by utilising on-demand routing in conjunction with source routing and route caching; nevertheless, in larger networks, it may encounter issues with scalability and huge packet headers.

The proposed Composite Adaptive Multipath Relay Node Selection (CAMRNS) algorithm is an advanced routing technique for MANETs that enhances reliability, energy efficiency, and adaptability in dynamic environments. Relay nodes are chosen using a composite score with adjustable weights for dynamic adaptation that takes into account factors such link quality, residual energy, node mobility, historical dependability, and distance to the destination. CAMRNS is perfect for high-mobility situations like disaster recovery and military operations because it builds numerous discontinuous relay pathways to provide fault tolerance and load balancing.

The Composite Adaptive Multipath Relay Node Selection (CAMRNS) algorithm is designed to identify and maintain an optimal set of relay nodes for reliable and energy-efficient multipath routing in dynamic networks. It operates on a given network topology by computing a composite score for each node that reflects its suitability as a relay. This composite score integrates multiple normalized metrics, including residual energy, link quality, reliability, hop count to the destination, node mobility, and link stability, each weighted by tunable parameters. By combining positive contributors such as high energy, strong links, and stable connectivity with penalties for excessive hop count and mobility, CAMRNS ensures that only robust and sustainable nodes are considered. Threshold conditions further filter candidate nodes to guarantee minimum energy, link quality, and reliability requirements before relay selection.

Once candidate relay nodes are identified, CAMRNS constructs a multipath relay set by ranking nodes according to their composite scores and selecting the top-performing candidates while ensuring path diversity and minimal overlap. The algorithm continuously monitors active paths during data transmission, adapting to performance degradation by recomputing composite scores and replacing weak relays in real time. Additional mechanisms for loop detection and redundancy elimination enhance routing efficiency and prevent unnecessary resource usage. Periodic re-evaluation of network conditions allows CAMRNS to respond effectively to topology changes, making it well suited for dynamic and mobile environments where reliability, stability, and energy conservation are critical.

Experimental Simulation Setup

The NS-3 simulator is a widely used discrete-event simulation tool in networking research. It supports diverse range of network types, including wired, wireless, and mobile Network, along with core protocols like TCP, UDP, and IP, as well as various routing algorithms. NS-3 enables the evaluation of key performance metrics such as packet delivery ratio, end-to-end delay, and throughput. It is the perfect platform for creating and testing new protocols because of its open-source design, which permits a great range of customisation and expansion. NS-3 is a vital tool for research and protocol innovation since it faithfully replicates real-world network settings (Riley and Henderson, 2010).

NS-3 Simulation Parameters

The parameters required to run the suggested method in the NS-3 simulator are tabulated in Table 1.

Results and Discussion

The performance of the suggested CAMRNS technique and the current approaches OLSR, AODV, and DSR is examined in this section using a variety of metrics, including packet delivery ratio, throughput, and end-to-end latency. A tabulation of the simulation results for various parameters is provided below, along with graphical results.

Packet Delivery Ratio (PDR)

The ratio of the number of packets successfully received by the destination to the number of packets sent by the source.

$$PDR(\%) = \left(\frac{\sum_{i=1}^{N} P_{recv}^{(i)}}{\sum_{i=1}^{N} P_{sent}^{(i)}} \right) X100$$

ere:

$P_{recv}^{(i)}$: Number of packets received by destination node i

: Total number of flows or source – destination pairs

Pseudocode 1: Composite Adaptive Multipath Relay Node Selection (CAMRNS)

```
Input: Input: Network topology G (N, E), N = nodes, E = links
    Source node S, Destination node D
    Thresholds: Energy_T, LinkQuality_T, Reliability_T
    Parameters: α, β, γ, δ, μ, v (α+β+γ+δ+μ+v=1)
Output: Set of optimal relay nodes R for multipath routing
Begin
{
Step 1: Composite metric definition
$CS(n) = \propto .E_{norm}(n) + \beta .LQ_{norm}(n) + \gamma .R_{norm}(n) - \delta .HC_{norm}(n) - \mu .M_{norm}(n) + \nu .LS_{norm}(n)\cdot$
ere
$\propto.E_{norm}(n)$:  Normalized residual energy
$\beta.LQ_{norm}(n)$: Normalized link quality (e.g., PRR/SNR)
γ.R_norm(n): Normalized reliability (packed forwarding success history)
$\delta.HC_{norm}(n)$: Normalized hop count to destination
$\mu.M_{norm}(n)$: Normalized node mobility (penalizes highly mobile nodes)
$v.LS_{norm}(n)$: Normalized link stability
Step 1a: Residual Energy Calculation
$E_{norm}(n) = \frac{E_{res}(n)}{E_{max}}\cdot$
ep 1b: Link Stability Calculation
Let link stability $LS(n_i, n_j)$ be based on link duration or variation in RSSI :
ep 1c: Node Mobility Calculation
Mobility is typically determined by changes in position throughout time:
$M(n) = \frac{1}{t}\sum_{i=1}^{t}\vec{P}_n(i) - \vec{P}_n(i-1)\ ,\ M_{norm}(n) = \frac{M_{(n)}}{M_{max}}\cdot$
gher mobility àless stable as relay à penalized in CS(n)

Step 2: Candidate relay node discovery
For each neighbor$n_i$ in source node S:
  If $E(n_i)$ > Energy_T and $LQ(n_i)$ > LinkQuality_T and $R(n_i)$ > Reliability_T:
    Calculate $CS(n_i)$
    Include $n_i$ to CandidateList
Step 3: Multipath set construction
Arrange CandidateList in descending order of CS
Choose top-K candidates to form a RelaySet R
Verify paths from S to D via each $r_i \in$ R are either disjoint or minimally overlapping
Step 4: Adaptive path monitoring and maintenance
While transmitting:
  For each path pi ∈ R:
    Monitor packet delivery ratio (PDR), delay, and energy consumption, stability and mobility
    If performance degrades below threshold:
Recompute CS for neighboring nodes
      Update RelaySet R by replacing low-performing relay
Step 5: Loop detection and redundancy elimination
For each selected path pi:
  Ensure no loop exists (using visited node list or sequence numbers)
  Avoid redundant relays (nodes appearing in multiple paths unnecessarily)
Step 6: Data transmission
```

Table 1: Simulation Parameters

Parameter	*Value*
Simulator	NS-3.38
Number of Nodes	50-100
Area Size	1000m × 1000m
Mobility Model	Random Waypoint Mobility
Energy Model	Basic Energy Source + Wifi Radio Energy Model
Routing Protocol	Modified OLSR (with CAMRNS)
Traffic Type	CBR over UDP
Simulation Time	200 seconds
Packet Size	512 bytes
Packet Interval	0.2s
Transmission Range	250 MHzHh

Based on the number of packets transmitted between 100 and 1000, the Packet Delivery Ratio (PDR) statistics for the protocols OLSR, AODV, DSR, and the planned CAMRNS is examined in depth here. The table 6.2 shown below presents the Packet Delivery Ratio for four routing protocols OLSR, AODV, DSR, and the proposed CAMRNS across varying numbers of data packets ranging from 100 to 1000. Packet Delivery Ratio is a key performance metric in measuring the percentage of successfully delivered packets to their destination out of the total packets sent. A higher PDR indicates better routing efficiency and network reliability.

The graph shows that CAMRNS achieves the highest Packet Delivery Ratio (PDR) of 96.1% at 100 packets, outperforming OLSR (89.5%), AODV (91.0%), and DSR (90.2%). As traffic increases to 1,000 packets, all protocols experience a decline in PDR due to congestion and overhead, with OLSR dropping to 76.5%, AODV to 78.2%, and DSR to 77.8%. CAMRNS, however, maintains a superior PDR of 89.3% at 1,000 packets, thanks to its adaptive multipoint relay selection that considers node mobility, link stability, and residual energy, along with centralized channel allocation, real-time congestion monitoring, and effective load balancing. These features enable CAMRNS to provide more reliable and efficient routing under heavy network load.

Table 2: Packet Delivery Ratio

Number of packets sent	*OLSR*	*AODV*	*DSR*	*CAMRNS*
	(in percentage - %)			
100	89.5	91.0	90.2	96.1
200	87.8	89.4	88.5	95.3
300	86.2	88.0	86.7	94.5
400	84.9	86.3	85.2	93.7
500	83.5	85.1	84.0	93.0
600	82.1	83.7	82.8	92.3
700	80.8	82.3	81.6	91.6
800	79.3	80.9	80.4	90.8
900	77.9	79.5	79.1	90.0
1000	76.5	78.2	77.8	89.3

The results presented in Table 2 and Figure 2 conclude that CAMRNS consistently achieves higher throughput than OLSR, AODV, and DSR under all traffic loads. As the number of packets increases, CAMRNS maintains better scalability and data transmission efficiency due to adaptive relay node selection, congestion-aware routing, and balanced traffic distribution. This demonstrates that CAMRNS is more suitable for high-load and real-time MANET applications where sustained throughput is essential.

Throughput

The average rate of successful message delivery over a communication channel, measured in bits per second (bps).

Formula:

$$Throughput\left(kbps\right) = \frac{\sum_{i=1}^{N} D_{recv}^{(i)} \; x\, 8}{T_{end} - T_{start}}$$

Total data received by destination i in bytes

$T_{end} - T_{start}$ Total simulation or measurement time in seconds

Multiply by 8 to converts bytes to bits

The Table 3 provided below presents throughput values (in kbps) for four routing protocols OLSR, AODV, DSR, and the proposed CAMRNS across a range of data packet loads, from 100 to 1000 packets. Throughput is a critical metric in MANET as it measures the successful delivery rate of data across the network, reflecting both efficiency and reliability. Throughput increases for all protocols as packet volume rises, but CAMRNS demonstrates significantly better scalability under heavy network loads. While OLSR, AODV, and DSR show throughput gains of 65%, 74%, and 74.4% respectively, they begin to plateau due to control-message overhead, route discovery delays, and header congestion. In contrast, CAMRNS achieves the highest increase from 144 kbps to 263 kbps (82.6%) by leveraging intelligent multipath relay selection, dynamic channel allocation, and real-time congestion monitoring. These adaptive features reduce collisions, balance network load, and ensure consistent data delivery even under dense traffic. As traditional protocols struggle with congestion and efficiency at scale, CAMRNS maintains superior throughput, making it highly suitable for mission-critical MANET applications requiring robust and high-speed communication.

End-to-End Delay

The End-to-End Delay (EED) is typically defined as the average time taken for a data packet to travel from the

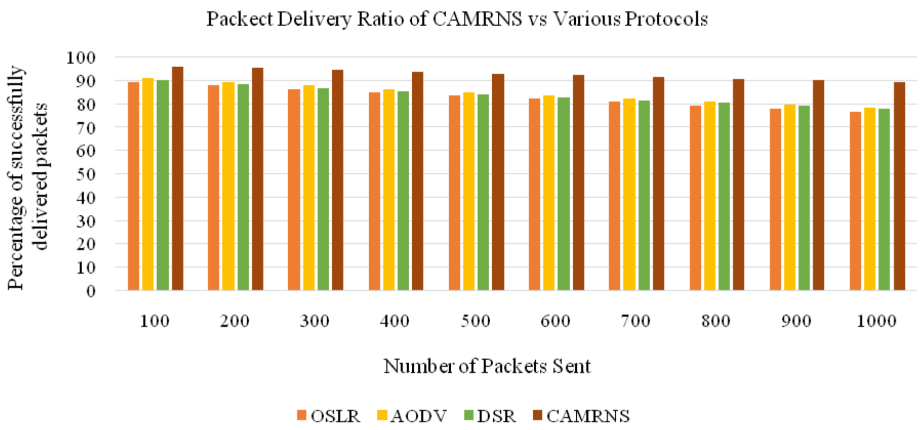

Figure 2: Packet Delivery Ratio Vs Number of data packets

source to the destination across a network. It can be calculated using the following formula.

$$End - to - End\ Delay = \frac{\sum_{i=1}^{N} (t_{r,i} - t_{s,i})}{N} .$$

ere

N = total number of successfully received packets

$t_{s,i}$ = timestamp when packet i was sent

$t_{r,i}$ = timestamp when packet i was received

The following Table 4 compares average end-to-end delay (ms) for OLSR, AODV, DSR, and CAMRNS as packet load grows from 100 to 1,000. Delay rises for all protocols under heavier traffic due to increased queuing, route discovery, and retransmissions, but the rate and magnitude differ markedly.

The Figure 4 indicates that while all protocols experience increasing end-to-end delay as packet load grows, CAMRNS consistently maintains the lowest and most stable delay, making it ideal for real-time MANET applications. OLSR, with its regular control-message overhead, sees delay rise from 190 ms to 245 ms; AODV, though more efficient initially, increases from 175 ms to 238 ms due to route discovery delays and link breakages; and DSR, burdened by source routing headers, grows from 182 ms to 243 ms. In contrast, CAMRNS rises modestly from 142 ms to just 174 ms, a 22.5% increase, thanks to its adaptive relay selection, congestion avoidance, and dynamic rerouting. These features enable CAMRNS to sustain low latency even under heavy traffic, outperforming traditional protocols that struggle with scalability and rising delays.

Compared to existing multipath relay node selection algorithms, CAMRNS approach demonstrates superior performance by integrating node mobility awareness, link stability assessment, and residual energy evaluation into a unified decision framework. Conventional algorithms typically rely on limited metrics, making them highly susceptible to dynamic topology changes caused by node mobility. This results in frequent route failures, repeated route rediscovery, increased retransmissions, and elevated collision probability, ultimately degrading packet delivery ratio (PDR), throughput, and end-to-end delay.

Table 3: Throughput

Number of Packets Sent	*OLSR*	*AODV*	*DSR*	*CAMRNS*
	(in Kilo Byte per second - kbps)			
100	122	129	125	144
200	135	142	138	158
300	145	155	150	173
400	155	168	162	186
500	165	180	172	200
600	172	190	183	213
700	180	200	192	226
800	188	208	201	239
900	195	217	210	251
1000	202	225	218	263

Table 4: Average End-to-End Delay

Number of packets sent	*OLSR*	*AODV*	*DSR*	*CAMRNS*
100	190	175	182	142
200	197	183	191	148
300	205	191	200	151
400	210	198	207	155
500	217	205	213	158
600	222	211	219	162
700	228	218	225	166
800	233	224	230	169
900	239	231	236	172
1000	245	238	243	174

In contrast, CAMRNS proactively mitigates these limitations by adaptively selecting relay nodes with stable links and sufficient residual energy, ensuring the formation

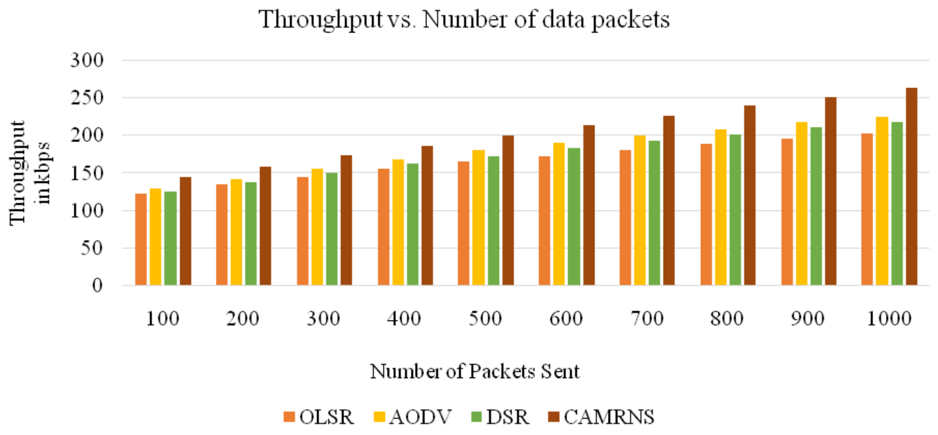

Figure 3: Throughput *vs* Number of data packets

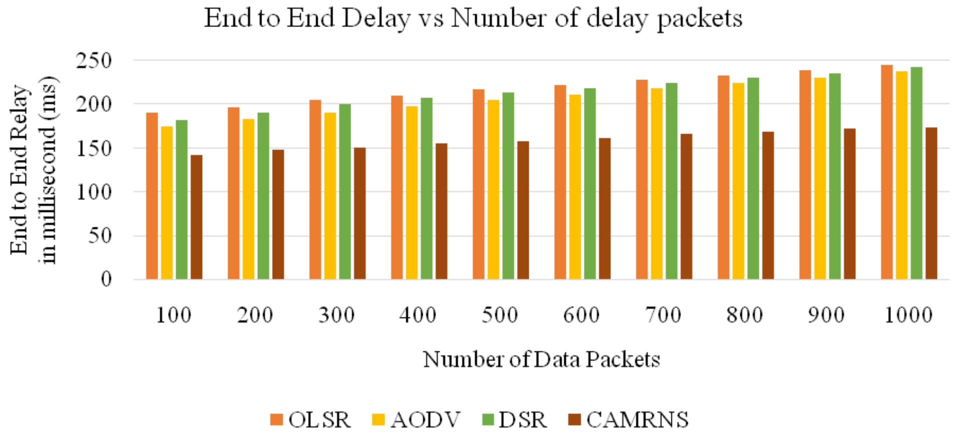

Figure 4: End-to-End Delay vs Number of Data Packets

of durable and reliable multipath routes. By emphasizing link stability, CAMRNS significantly reduces link breakages and routing overhead when compared to mobility-agnostic or shortest-path-based schemes. This stability directly translates into fewer collisions, reduced route interruptions, and improved throughput and latency performance.

Furthermore, unlike energy-unaware relay selection methods that experience sudden path failures due to node energy depletion, CAMRNS incorporates residual energy as a core selection parameter. This enables sustained data forwarding and prevents premature node failures, thereby maintaining higher PDR and minimizing delays associated with route reconstruction. The composite weighting of mobility, link quality, and energy allows CAMRNS to dynamically adapt to network conditions, outperforming static or single-metric approaches in highly dynamic and resource-constrained MANET environments.

Overall, CAMRNS offers a more reliable, adaptive, and energy-efficient routing solution than existing algorithms, making it particularly suitable for real-time and mission-critical MANET applications where stability, efficiency, and resilience are essential.

Conclusion

This research introduces CAMRNS, a novel multipath relay node selection strategy designed to improve routing efficiency and reliability in MANETs. Simulations show that CAMRNS consistently outperforms traditional protocols like OLSR, AODV, and DSR by reducing collisions and retransmissions, improving throughput, delivery ratio, and lowering end-to-end delays, especially under heavy traffic and high-mobility conditions, thereby enabling more efficient and reliable MANET communication. By integrating factors such as node mobility, residual energy, and link stability into a dynamic selection metric, CAMRNS effectively reduces packet loss, minimizes collisions, and ensures stable, low-interference paths. Its adaptive relay selection, real-time congestion monitoring, and load balancing capabilities enable efficient rerouting around network bottlenecks, making it highly suitable for mission-critical applications like military and disaster response. These results demonstrate CAMRNS's robustness and efficiency, with future enhancements aimed at incorporating machine learning for adaptive optimization.

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