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Enhancing Stability and Efficiency in Mobile Ad Hoc Networks (MANETs): A Multicriteria Algorithm for Optimal Multipoint Relay Selection

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Abstract: Mobile ad hoc networks (MANETs) are autonomous systems composed of multiple mobile nodes that communicate wirelessly without relying on any pre-established infrastructure. These networks operate in highly dynamic environments, which can compromise their ability to guarantee consistent link lifetimes, security, reliability, and overall stability. Factors such as mobility, energy availability, and security critically influence network performance. Consequently, the selection of paths and relay nodes that ensure stability, security, and extended network lifetimes is fundamental in designing routing protocols for MANETs. This selection is pivotal in maintaining robust network operations and optimizing communication efficiency. This paper introduces a sophisticated algorithm for selecting multipoint relays (MPRs) in MANETs, addressing the challenges posed by node mobility, energy constraints, and security vulnerabilities. By employing a multicriteria-weighted technique that assesses the mobility, energy levels, and trustworthiness of mobile nodes, the proposed approach enhances network stability, reachability, and longevity. The enhanced algorithm is integrated into the Optimized Link State Routing Protocol (OLSR) and validated through NS3 simulations, using the Random Waypoint and ManhattanGrid mobility models. The results indicate superior performance of the enhanced algorithm over traditional OLSR, particularly in terms of packet delivery, delay reduction, and throughput in dynamic network conditions. This study not only advances the design of routing protocols for MANETs but also significantly contributes to the development of robust communication frameworks within the realm of smart mobile communications.

Keywords: mobile ad hoc networks; optimized link state routing protocol; multipoint relays selection; mobility; security; energy; NS3; IoT

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1. Introduction

Wireless technology has greatly improved operators' ability to access information conveniently, regardless of location and time [1]. This led to the development of mobile ad hoc networks (MANETs), which enable mobile nodes to collaborate and form temporary networks without centralized control [2,3]. MANETs are essential in environments lacking fixed infrastructures, such as disaster recovery and city surveillance. Despite challenges like high packet loss and frequent route interruptions due to limited resources and dynamic topologies, MANETs offer a valuable solution [4–6].

Studies [7,8] highlight how node mobility impacts network performance and emphasize the need for adaptive, self-configuring protocols. These studies categorize routing protocols as proactive, reactive, or hybrid, each designed to meet specific performance criteria [7–10]. Proactive protocols, such as OLSR, keep network routes updated continuously but may incur high overhead. Reactive protocols, such as DSR and AODV, dynamically establish routes on demand, resulting in reduced overhead but potentially increased delays. On the other hand, hybrid protocols combine the strengths of both [9,10].

The rise of smart cities has driven advances in multihop ad hoc wireless networks (MAWNs), such as MANETs, wireless sensor networks (WSNs), vehicular ad hoc networks (VANETs), and wireless mesh networks (WMNs) [11]. These technologies support Internet of Things (IoT) applications by connecting devices across diverse networks. In smart environments, integrating IoT with MANETs and WSNs enhances mobility, reduces deployment costs, and improves localized data transmission [12].

Routing remains a critical challenge in MANETs due to frequent topology changes and the distributed nature of the network. Routing protocols, such as OLSR, use multipoint relays (MPRs) to optimize routing and minimize control traffic [13,14]. However, mobility, energy, and security issues affect node stability, requiring better MPR selection mechanisms [15,16]. Our multicriteria adaptive MPR selection algorithm addresses these challenges by selecting stable and trusted MPRs based on energy, trust, and mobility, improving network performance as shown in NS3 simulations with Random Waypoint and Manhattan Grid models [17–20].

The insight behind our work stems from the inherent challenges in MANETs, where frequent topology changes, resource constraints, and security vulnerabilities affect network performance, particularly in routing. Traditional MANET routing protocols, while effective under certain conditions, struggle with maintaining network stability, reachability, and efficiency in highly dynamic environments. The Optimized Link OLSR, specifically its MPR selection mechanism, plays a key role in minimizing control traffic. However, the current MPR selection strategies often fail to consider critical factors such as node mobility, energy levels, and trustworthiness. This leads to frequent MPR modifications, increased network overhead, and degraded network performance in dynamic and resource-constrained environments.

The motivation of our work lies in addressing these gaps by introducing a multicriteria-based adaptive MPR selection algorithm. Unlike previous works that focus on single criteria (e.g., mobility or energy), our proposed scheme integrates mobility, energy, and trust metrics to enhance the stability and reliability of selected MPRs. This approach significantly reduces the frequency of MPR re-affiliations, thereby lowering overhead, and improving overall network performance, particularly in high-mobility environments. Compared to existing schemes, our algorithm improves packet delivery ratios (PDR), reduces delay, and lowers packet loss rates, as validated through extensive NS3 simulations using Random Waypoint and Manhattan Grid mobility models. Furthermore, by incorporating trust metrics, our approach enhances network security, leading to more reliable communication, especially in environments prone to malicious activity. Existing MPR selection algorithms often do not sufficiently address the importance of trust metrics, potentially compromising network integrity.

To summarize, this study presents several key contributions, including the following:

- An improved MPR selection algorithm for MANETs based on multiple criteria: energy, mobility, and trust.
- A multicriteria weighted function that reduces MPR changes, minimizes network overhead and improves energy efficiency.
- Enhanced network performance, demonstrated through NS3 simulations using Random Waypoint and ManhattanGrid mobility models, showing better PDR, lower delays, and reduced packet loss.
- Adaptability to high-mobility environments, ensuring reliable data relay even under frequent topological changes.
- Trust metrics to strengthen network security, providing better protection against threats.
- Comprehensive simulation results validating the effectiveness of the multicriteria-weighted MPR selection method.

The rest of the paper is organized as follows. Section 2 delves into related works to contextualize this study within the existing body of knowledge. Section 3 presents a detailed explanation of the proposed multicriteria-weighted MPR selection methodology, breaking down the technical aspects of the algorithm and outlining the metrics used for evaluation. Extensive simulations and analyses are then presented in Section 4 to demonstrate the efficacy of the proposed algorithm, comparing it against traditional methods using various performance metrics. The paper concludes with a summary of findings and potential directions for future research in Section 5, suggesting ways this work could be extended or refined.

2. Related Works

This section reviews studies focused on mobility, energy, security, and weighted techniques in MANETs. To begin with, MPR nodes broadcast TC messages to establish communication between sources and destinations. Thus, optimizing MPR selection is crucial for improving network performance. Notably, the OLSR protocol and MPR selection can be enhanced by incorporating additional criteria into the MPR mechanism [21,22]. Mobility, energy, and trust metrics play a significant role in routing protocol performance in dynamic environments. Several studies have analyzed these factors and quantified their impact using multiple metrics. Moreover, the importance of effective data routing in IoT environments and MANET-WSN convergence has been highlighted [23]. Deploying MANET nodes in such scenarios reduces latency and overcomes WSN limitations like low data rates and limited battery capacity. While MANET nodes have energy constraints, they offer higher bandwidth and lower latency, making them advantageous for critical data transmission.

In addition, the hybrid multipath energy and QoS-aware OLSR protocol (MEQSA-OLSRv2) [24] addresses challenges such as limited energy, mobility, and congestion in MANET-WSN scenarios by using a multicriteria node rank metric (MCNR). It optimizes link quality and selects MPR sets based on energy and QoS, significantly outperforming existing schemes in high-traffic and mobility situations. However, reachability and stability are further challenged by node mobility. To address this, a topology-based protocol [25] was developed to enhance VANET performance. Simulations confirmed that the choice of protocol depends on network size and desired metrics. Similarly, other studies have improved MPR selection and routing efficiency by addressing issues like redundant HELLO and TC messages and delayed routing updates [26–28].

Furthermore, several advanced algorithms, such as the continuous Hopfield network (CHN) [29] and 3D position-based modified OLSR [30], have demonstrated improvements in packet delivery ratio (PDR), throughput, and routing overhead. In parallel, clustering techniques like ACRP and EECRPSID have been employed to optimize clustering and eliminate redundant data [31,32]. For instance, the ANFC-QGSOR protocol [33] combines clustering and optimization to improve performance in VANETs. On the other hand, energy-aware algorithms, such as those proposed in [34,35], focus on balancing network load and extending network lifetime. Additionally, security enhancements, such as novel MPR selection algorithms to avoid malicious nodes [36], have improved throughput and reduced packet loss. Similarly, studies on V2X security [37] and hybrid secure cluster-based algorithms [38] have demonstrated better performance in simulations.

In terms of weighted clustering, several studies have proposed weighted techniques for enhanced performance. For example, weighted clustering techniques [39,40] and multi-objective OLSR optimization [41] have further improved network performance by reducing packet loss and delay. Additionally, a study combining residual energy and reachability for optimal MPR selection [42] showed improved network lifetime. Finally, a new multicriteria-weighted MPR (MCWMPR) scheme has been integrated into the OLSR protocol to enhance MPR selection based on multiple metrics [43], demonstrating a significant improvement over traditional approaches.

The proposed method aims to address the gaps identified in previous studies by introducing an adaptive, multicriteria MPR selection algorithm that integrates mobility, energy, and trust metrics. Unlike existing methods that focus on single criteria, this approach combines these key factors to improve the stability and reliability of MPR selection in highly dynamic environments. Furthermore, by reducing the frequency of MPR re-affiliations and minimizing network overhead, our method tackles the limitations associated with frequent topology changes and energy constraints. By incorporating trust metrics, the proposed algorithm also enhances security, ensuring more reliable communication in scenarios vulnerable to malicious activity. Thus, our work effectively fills the gaps related to network stability, security, and efficiency in high-mobility MANET environments.

3. Proposed Methdolgy

MANETs inherently suffer from unpredictable node mobility, limited energy resources, and security vulnerabilities. These dynamic networks face significant challenges in maintaining reliable communication and network performance as nodes frequently move, join, or leave. To address these issues, we propose an advanced multicriteria stability mechanism that assesses and enhances node stability. This mechanism considers key factors like node mobility, energy availability, and security profiles to improve the selection of MPRs, aiming for more stable and efficient network routing. By systematically evaluating these metrics, our approach mitigates the inherent instabilities of MANETs, leading to enhanced network resilience and reliability.

3.1. Brief Description of OLSR

The OLSR protocol is a table-driven routing protocol specifically developed for MANETs. It simplifies routing logic and offers high efficiency. Nodes in OLSR transmit Hello messages to their 1-hop neighbors, electing a set of MPRs, as illustrated in Figure 1. Only MPRs forward topological information and create link-state information. OLSR is especially effective in large and dense networks. However, selecting the minimum set of MPRs poses challenges, making it necessary to explore algorithms that optimize this selection process. Table 1 presents the structure of a standard Hello message used in the Optimized Link State Routing (OLSR) protocol within a Mobile Ad Hoc Network (MANET).

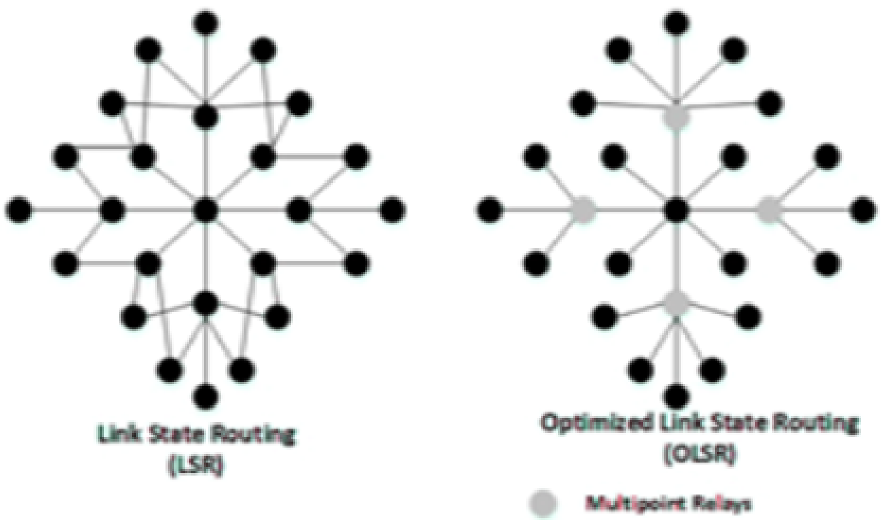

Figure 1. Multipoint relays illustration.

Table 1. Standard Hello message in OLSR Protocol.

Reserved	Htime	Willingness
Link code	Reserved	Link Message Size
	Neighbor Interface Address	

Through Hello messages, the OLSR protocol defines 2-hop neighbors and accomplishes a distributed election of a set of MPRs. When a node is selected as an MPR, there is always a path to each of its 2-hop neighbors. OLSR offers the best paths in terms of the number of hops and is particularly suitable for large and dense networks. The OLSR routing protocol presents several restrictions regarding the calculation of the minimum MPRs (NP-complete problem). Hence, defining a node's MPRs is an interesting problem, and some algorithms should be used to find the optimal result.

3.2. Terminology and Introduction of the Improvement

Building on existing studies, we developed a multicriteria stability mechanism called Multicriteria Weighted MPR (MCWMPR) for optimal MPR selection within the OLSR protocol. MCWMPR evaluates the mobility patterns, energy levels, and trustworthiness between nodes. Nodes with similar mobility, high energy, and mutual trust are more likely to maintain stable connections and stay cohesive over time. Table 2 defines the key terms associated with this improvement.

Table 2. Terminology of the improvement.

Terminology	Description	Unit of Measure
D	Distance	[m]
S	Node's speed	[m/s]
θ	Node's direction	[°]
V	Velocity	[m/s]
A	Acceleration	[m/s^2]
ΔT	Time interval	[s]
t	Current time	[s]
$RS(i,j)$	Relative speed	-
$RA(i,j)$	Relative acceleration	-
$RD(i,j)$	Relative direction	-
SD	Spatial dependency	-
$E(i,j)$	Residual energy	-
$EARE$	Average residual energy	-
LE	Energy level	-
PS	Packets sent	-
PR	Packets received	-
TM	Trust measure	-
$MCWMPR$	Multicriteria Weighted MPR	-

3.3. Description of the Proposed Approach

In the Optimized Link State Routing (OLSR) protocol, MPR(S), $N(S)$, and $N2(S)$ represent the MPR, 1-hop neighbors, and 2-hop neighbors of node S, respectively. These sets are calculated following the standard OLSR protocol. The mobile ad hoc network (MANET) is modeled as a directed graph $G(U,E)$, where U is the set of nodes and E is the set of links. A link $l = (i,j)$ exists if node j is within the transmission range of node i.

At each time interval ΔT, the changes in the x- and y-coordinates, ΔxT and ΔyT, of a node can be computed as follows:

$$\Delta xT_i = (x_{ti} - x_{Ti})$$

$$\Delta yT_i = (y_{ti} - y_{Ti})$$

where t is the current time, and x_{ti}, y_{ti}, x_{Ti}, and y_{Ti} are the spatial coordinates of node i at times t and T.

The Euclidean distance D between the current and previous positions of a node is calculated as

$$D = \sqrt{(\Delta xT)^2 + (\Delta yT)^2} = \sqrt{(x_{ti} - x_{Ti})^2 + (y_{ti} - y_{Ti})^2}$$

Consequently, the speed S of the node over the time interval ΔT is determined by

$$S = \frac{D}{\Delta T} = \frac{\sqrt{(x_{ti} - x_{Ti})^2 + (y_{ti} - y_{Ti})^2}}{T - t}$$

This calculation helps in determining the mobility pattern of the nodes, which plays a critical role in the proposed multicriteria MPR selection approach.

3.4. Improved Scheme

The direction (θ) of a node is defined as

$$\theta_i = \begin{cases} \varphi \cdot \sin(\Delta yT_i) & \text{if } \Delta xT_i > 0 \\ \frac{\pi}{2} \cdot \sin(\Delta yT_i) & \text{if } \Delta xT_i = 0 \\ \pi - \varphi \cdot \sin(\Delta yT_i) & \text{if } \Delta xT_i < 0 \end{cases}$$

where $\tan(\varphi) = \left|\frac{\Delta yT_i}{\Delta xT_i}\right|$ and $\theta_i \in (-\pi, \pi)$.

The acceleration (A) of a node over time ΔT, based on the velocity (V), which combines speed and direction, is calculated as

$$A = \frac{\Delta v}{D}$$

3.5. Implementation Steps

Using these values, the multicriteria-weighted MPR (MCWMPR) is calculated through the following steps:

- **Step 1: Mobility information exchange.** Nodes exchange their mobility characteristics, such as speed and direction, with their directly connected neighbors via Hello packets, as shown in Table 3.

Table 3. Standard Hello message in OLSR Protocol.

Reserved	Htime	Willingness
Link code	Reserved	Link Message Size
Speed	TM	LE
Acceleration	Direction	MCWMPR
Neighbor Interface Address		
Neighbor Interface Address		

- **Step 2: Calculation of relative metrics.** A node calculates its Relative Speed (RS), Relative Acceleration (RA), and Relative Direction (RD) with its directly connected neighbors. For nodes i and j, these metrics are computed as follows:

$$RS_{(i,j,t)} = \log\left(1 - \frac{|S_i - S_j|}{S_{max}}\right)$$

where S_{max} is the maximum speed.

$$RD_{(i,j,t)} = \cos(\theta_i(t) - \theta_j(t))$$

$$RA_{(i,j,t)} = \log\left(1 - \frac{|A_i - A_j|}{A_{max}}\right)$$

where A_{max} is the maximum acceleration.

- **Step 3: Spatial Dependency calculation.** The Spatial Dependency (SD) between node i and node j is computed as

$$SD_{(i,j,t)} = RS_{(i,j,t)} \times RA_{(i,j,t)} \times RD_{(i,j,t)}$$

- **Step 4: Energy level calculation.** The energy level of each node is calculated as

$$LE_{(i,j,t)} = \frac{E_{(i,j,t)}}{E_{ARE}}$$

where $E_{(i,j,t)}$ is the residual energy of node i at time t, and E_{ARE} is the average residual energy of the node's neighbors.

- **Step 5: Trust measure calculation.** Trust is essential for secure communication. The trust measure $TM_{(i,j,t)}$ between two nodes is calculated as

$$TM_{(i,j,t)} = \frac{PS_{(i,j,t)}}{PR_{(i,j,t)}}$$

where PS and PR represent the number of packets sent and received, respectively. The trust measure helps identify and avoid malicious nodes.

- **Step 6: MCWMPR calculation.** Finally, the multicriteria-weighted MPR (MCWMPR) for a node is calculated as

$$MCW_{MPR(i,t)} = W1 \cdot \frac{1}{n}\sum_{j=1}^{n} SD_{(i,j,t)} + W2 \cdot \frac{1}{n}\sum_{j=1}^{n} LE + W3 \cdot \frac{1}{n}\sum_{j=1}^{n} TM_{(i,j,t)}$$

where $W1 + W2 + W3 = 1$, and the weighting factors are chosen according to the desired network performance criteria.

A lower MCWMPR value indicates that node i has a larger neighbor set, shares a similar mobility pattern with its neighbors, has high energy levels, and is a trusted measure, all contributing to improved network stability. Speed, direction, acceleration, energy, and security are strongly interrelated. Consequently, a node with a low MCWMPR value is eligible to be an MPR, which can enhance stability, and improve connection quality, reachability, and security, making the routing applicable in highly mobile environments. Figure 2 illustrates modified multipoint relays. Moving on, Algorithm 1 summarizes the improved scheme described above.

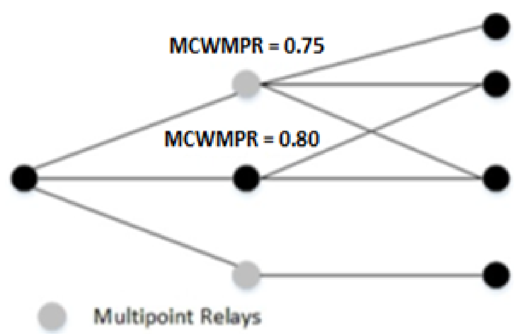

Figure 2. Modified multipoint relays illustration.

Algorithm 1: Multicriteria-weighted MPR (MCWMPR) Calculation

Input: Node i and its neighbors, mobility features (speed, direction, acceleration), energy levels, trust measures
Output: MCWMPR for node i
Step 1: Mobility Information Exchange;
Nodes exchange speed, direction, acceleration, and other metrics with neighbors via Hello packets;
Step 2: Calculation of Relative Metrics;
for *each neighbor j of node i* **do**
  Calculate Relative Speed (RS):;
  $RS_{(i,j,t)} = \log\left(1 - \frac{|S_i - S_j|}{S_{max}}\right);$
  Calculate Relative Direction (RD):;
  $RD_{(i,j,t)} = \cos(\theta_i(t) - \theta_j(t));$
  Calculate Relative Acceleration (RA):;
  $RA_{(i,j,t)} = \log\left(1 - \frac{|A_i - A_j|}{A_{max}}\right);$
end
Step 3: Spatial Dependency Calculation;
For each neighbor j, compute Spatial Dependency (SD):;
$SD_{(i,j,t)} = RS_{(i,j,t)} \times RA_{(i,j,t)} \times RD_{(i,j,t)};$
Step 4: Energy Level Calculation;
For each neighbor j, compute energy level (LE):;
$LE_{(i,j,t)} = \frac{E_{(i,j,t)}}{E_{ARE}};$
Step 5: Trust Measure Calculation;
For each neighbor j, compute trust measure (TM):;
$TM_{(i,j,t)} = \frac{PS_{(i,j,t)}}{PR_{(i,j,t)}};$
Step 6: MCWMPR Calculation;
Compute the final MCWMPR for node i:;
$MCW_{MPR(i,t)} = W1 \cdot \frac{1}{n}\sum_{j=1}^{n} SD_{(i,j,t)} + W2 \cdot \frac{1}{n}\sum_{j=1}^{n} LE + W3 \cdot \frac{1}{n}\sum_{j=1}^{n} TM_{(i,j,t)};$
where $W1 + W2 + W3 = 1$;
return MCWMPR value;

4. Results and Analysis

4.1. Simulation Mobility Model

The study is conducted in a C++ environment using the NS3 simulator [44], based on the Random Waypoint and ManhattanGrid mobility models for MANETs to evaluate the performance of routing protocols. The authors compare the performance of various scenarios of MCW_OLSR and OLSR. The simulation is executed for 100 s. Identical mobile nodes numbering 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 are arranged in a terrain of 1000 m by 1000 m. An examination of graphs is presented to discuss simulation results. Table 4 summarizes all parameters used during the simulation.

Table 4. Simulation parameters.

Parameters	Values
Terrain Size	1000 m × 1000 m
Max Number of Nodes	10, 20, 30, 40, 50, 60, 70, 80, 90, 100
Radio Range	250 m
MAC Layer	IEEE 802.11 peer-to-peer mode

Table 4. *Cont.*

Parameters	Values
Transport Layer	User Datagram Protocol (UDP)
Traffic Model	CBR
Packet Size	1024 bytes
Rate	0.4
Mobility Models	Random Waypoint and Manhattan Grid
Pause Time	1 s
Maximum Node Speed	25 m/s
Simulation Time	100 s

4.2. Comparison and Discussion

4.2.1. Random Waypoint Results

The graphs below illustrate the impact of the number of nodes on Delay, Jitter, Packet Delivery Ratio (PDR), Packet Loss Ratio (PLR), Throughput, and Lost Packets. It can be observed that MCW_OLSR shows improvements compared to OLSR, DSDV, and SR_OLSR, particularly in networks with a larger number of nodes. These results demonstrate the effectiveness of MCW_OLSR in dense network scenarios.

In Figure 3, the time taken for data packets to travel from source to destination is examined. The results indicate that MCW_OLSR offers a lower delay compared to OLSR, DSDV, and SR_OLSR. This improvement can be attributed to the enhanced stability, security, and longevity of the nodes, resulting in more efficient and stable connections with direct neighbors. This method ensures that paths remain valid and secure with optimal linking.

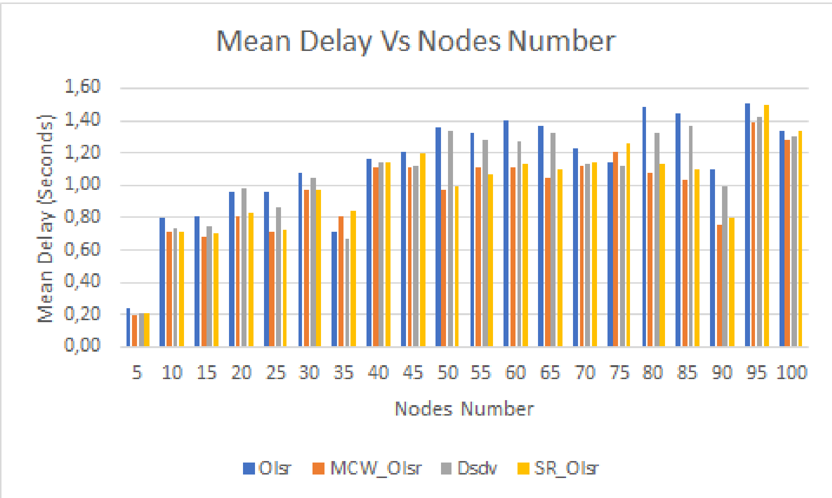

Figure 3. Mean Delay comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

The jitter is decreased due to the multicriteria-weighted MPR scheme. In this context, MCW_OLSR exhibits lower jitter compared to OLSR, DSDV, and SR_OLSR, as shown in Figure 4. This improvement suggests that the technique provides a distinct advantage in broadcast and communication, especially in scenarios with a higher number of mobile nodes.

Compared to OLSR, DSDV, and SR_OLSR, the MCW_OLSR protocol demonstrates a lower value of the PLR, as presented in Figure 5. This is due to the improved link stability and reliability between mobile nodes, which supports the successful transmission of packets.

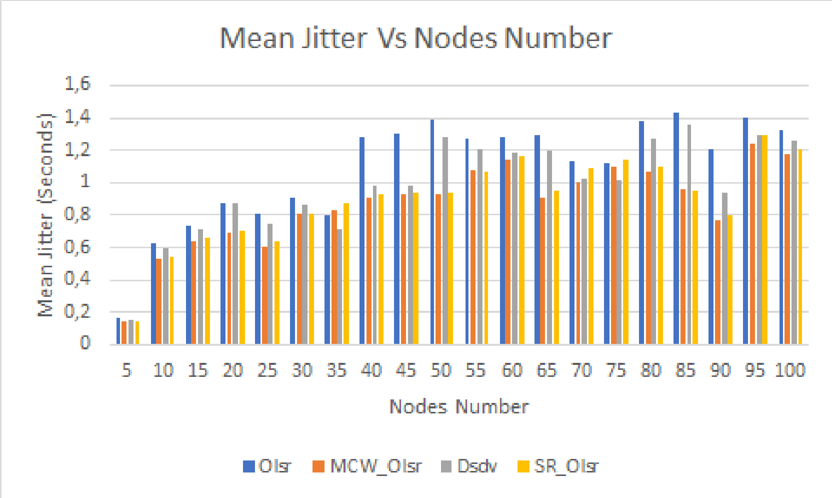

Figure 4. Mean Jitter comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

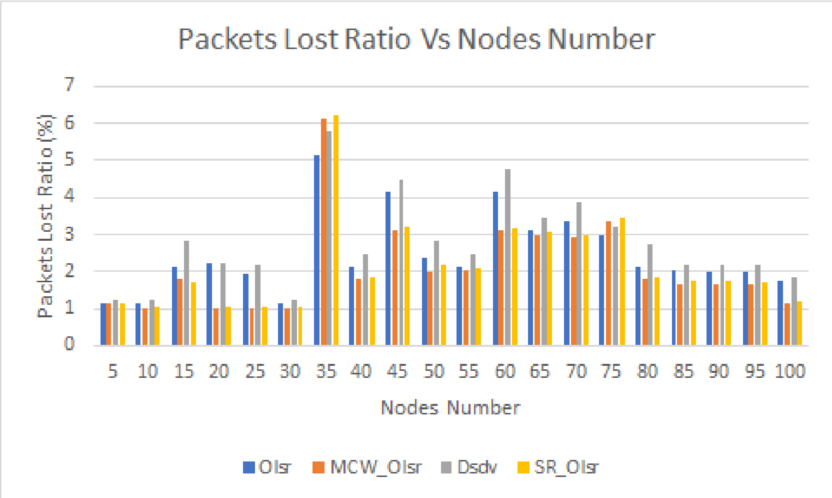

Figure 5. PLR comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

Figure 6 compares the packets successfully broadcasted by the protocols. Even in a dense network, MCW_OLSR achieves a better distribution of packets compared to OLSR, DSDV, and SR_OLSR. The graph confirms that MCW_OLSR performs well in terms of PDR.

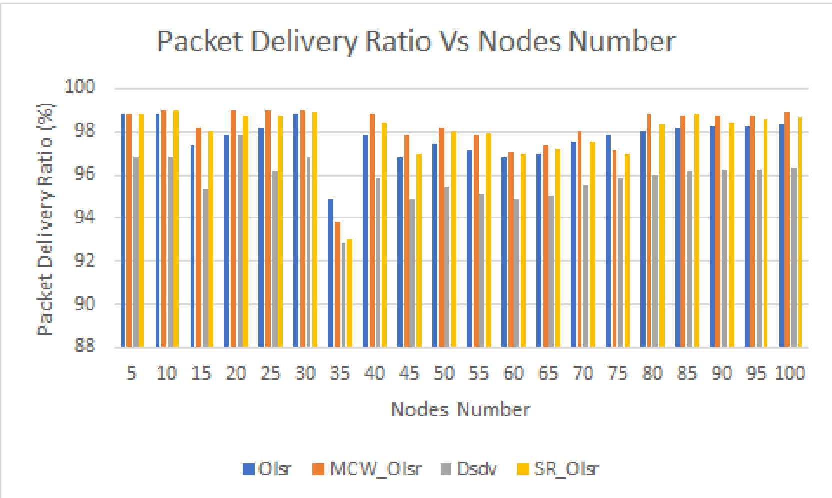

Figure 6. PDR comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

Figure 7 shows the comparison of lost packets. The number of lost packets in MCW_OLSR is negligible compared to OLSR, DSDV, and SR_OLSR. The improved link quality, link duration, and overall stability help avoid frequent broken links between mobile nodes.

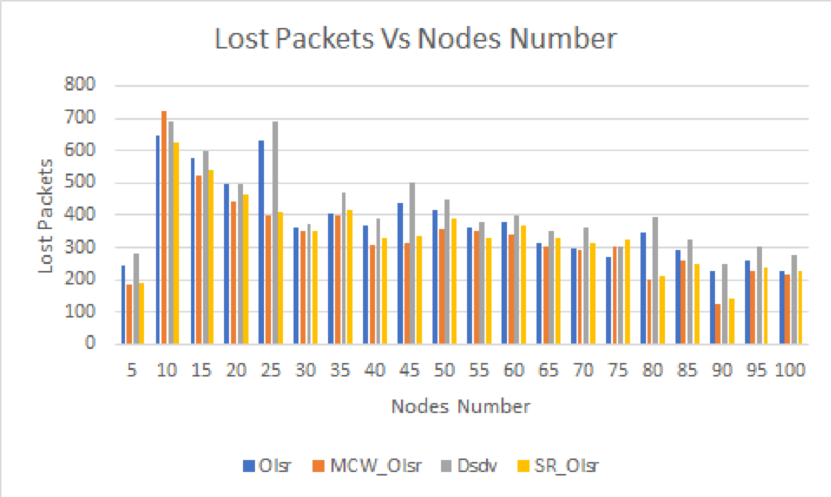

Figure 7. Lost Packets comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

Figure 8 presents the impact of the number of nodes on throughput. The MCW_OLSR protocol, integrated into the selection of MPRs, offers improved throughput compared to OLSR, DSDV, and SR_OLSR. Hence, the multicriteria-weighted MPR technique supports successful packet transmission.

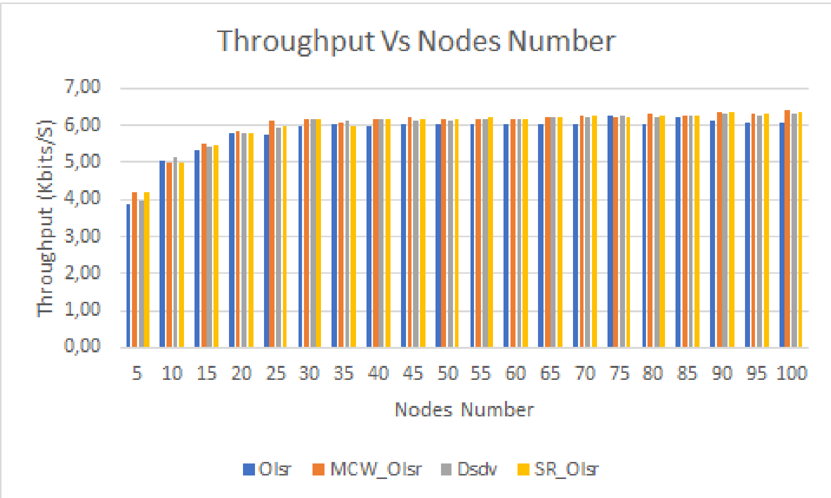

Figure 8. Throughput comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

4.2.2. ManhattanGrid Results

The graphs below illustrate the impact of the number of nodes on Delay, Jitter, PDR, PLR, Throughput, and Lost Packets. It can be observed that MCW_OLSR shows improvements compared to OLSR, DSDV, and SR_OLSR, particularly in networks with a larger number of nodes. These results demonstrate the effectiveness of MCW_OLSR in dense networks.

In Figure 9, the time taken for data packets to travel from source to destination is examined. The results indicate that MCW_OLSR offers a lower delay compared to OLSR, DSDV, and SR_OLSR. This improvement is due to enhanced node stability, security, and longevity, which ensures stable connections with direct neighbors.

Jitter is decreased due to the multicriteria-weighted MPR scheme. MCW_OLSR exhibits lower jitter compared to OLSR, DSDV, and SR_OLSR, as shown in Figure 10. This improvement confirms the advantage of the proposed technique in dense and mobile environments.

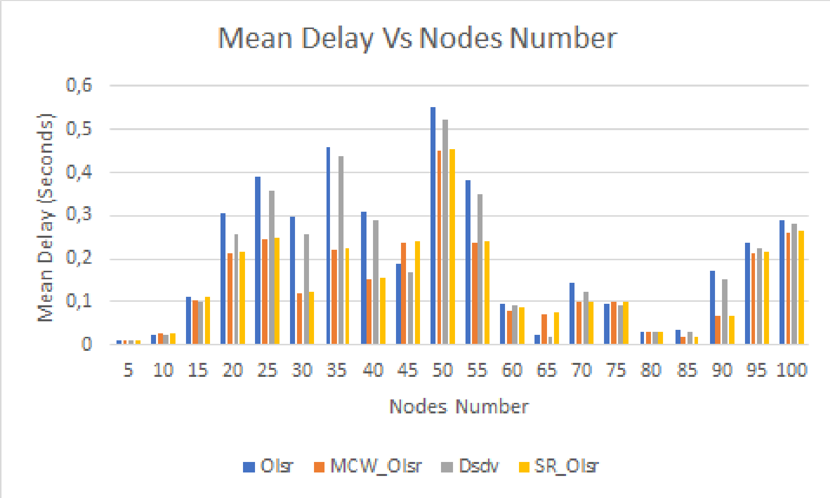

Figure 9. Mean Delay comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

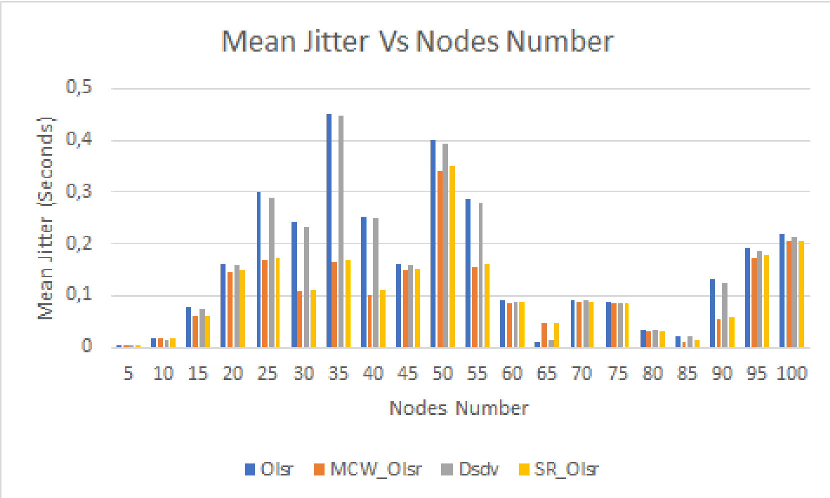

Figure 10. Mean Jitter comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

Compared to OLSR, DSDV, and SR_OLSR, the MCW_OLSR protocol demonstrates a lower PLR value, as presented in Figure 11. This is due to the enhanced link stability and node reliability, ensuring successful packet transmission.

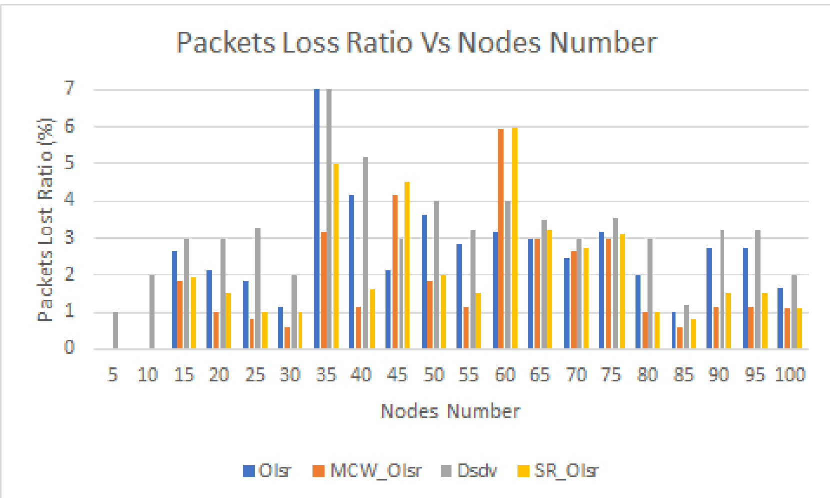

Figure 11. PLR comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

Figure 12 compares the packets successfully broadcasted by all protocols. MCW_OLSR achieves better packet distribution compared to OLSR, DSDV, and SR_OLSR. This shows that MCW_OLSR performs well in terms of PDR.

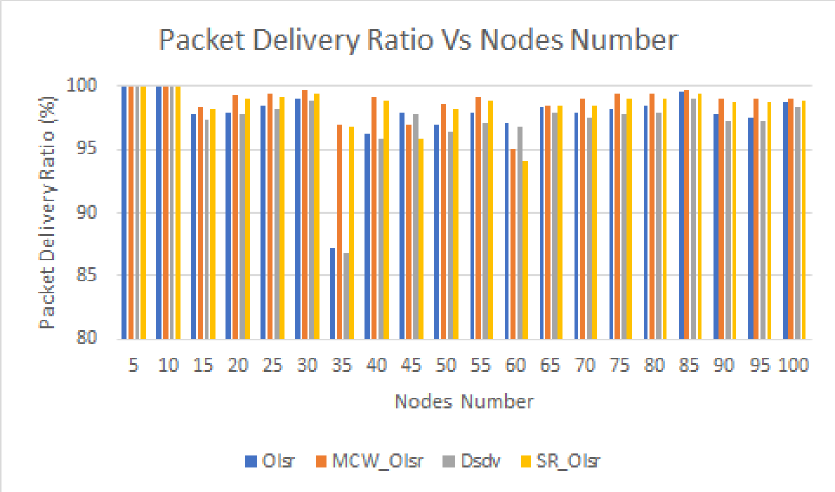

Figure 12. PDR comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

Figure 13 shows the comparison of lost packets. The number of lost packets in MCW_OLSR is negligible compared to OLSR, DSDV, and SR_OLSR. The stability of the links and reachability play a key role in avoiding frequent broken links in mobile environments.

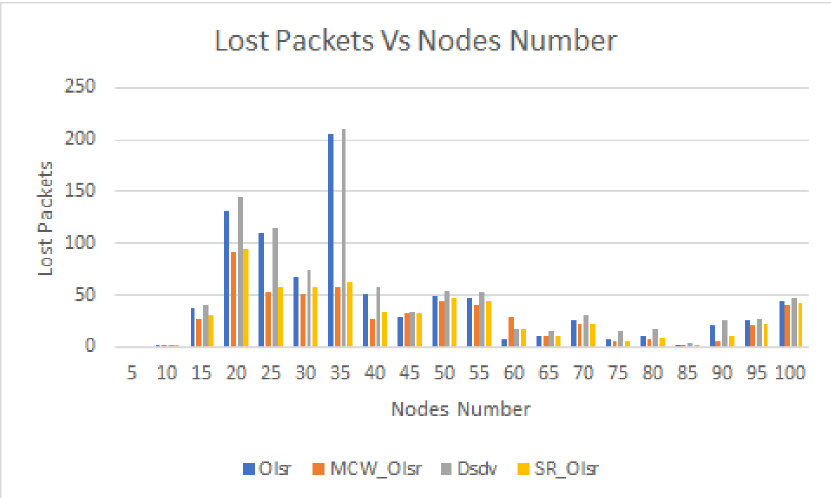

Figure 13. Lost Packets comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

Figure 14 presents the impact of the number of nodes on throughput. MCW_OLSR, by optimizing the selection of MPRs, shows a marked improvement in throughput compared to OLSR, DSDV, and SR_OLSR.

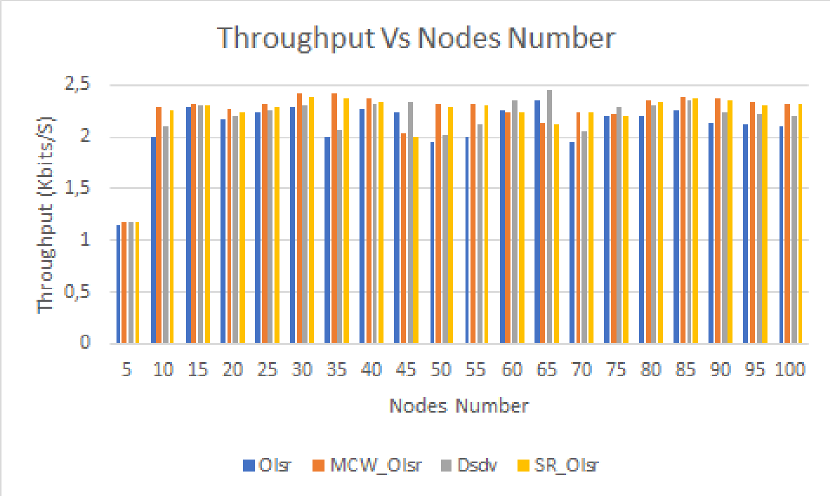

Figure 14. Throughput comparison between MCW_OLSR, OLSR, DSDV, and SR_OLSR.

5. Conclusions

In this study, we proposed a sophisticated MPR selection algorithm that leverages a multicriteria-weighted approach, taking into account the mobility, energy levels, and trust metrics of mobile nodes. This approach addresses the key challenges of mobility, energy constraints, and security vulnerabilities in MANETs, leading to improvements in network reachability, stability, and longevity. By employing this innovative method, we ensure superior network performance, with enhanced link stability and security.

The MCW_OLSR protocol was extensively compared against three SOTA baselines, including the original OLSR, DSDV, and SR_OLSR protocols. The results demonstrate that our multicriteria-weighted MPR selection method consistently outperforms these traditional protocols, particularly in dynamic and dense network environments. MCW_OLSR achieved significant improvements in terms of reduced packet loss, lower delay, decreased jitter, enhanced PLR, increased PDR, and improved overall throughput across both the Random Waypoint and ManhattanGrid mobility models.

The superior performance of MCW_OLSR highlights the effectiveness of integrating mobility, energy, and trust metrics into the MPR selection process. This leads to more reliable and efficient communication, making it a robust solution for highly dynamic MANET environments.

Future work will focus on refining the multicriteria function by incorporating additional parameters, such as node density and link quality. Additionally, we will explore the integration of machine learning techniques to predict and adapt to network dynamics proactively, further improving the adaptability and performance of the proposed algorithm in more complex scenarios.

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Abbreviations

Abbreviation	Full Form
3D-OLSR	3D Position-based Modified Optimized Link State Routing
5G	Fifth Generation Mobile Networks
ACRP	Adaptive Clustering-based Routing Protocol
AODV	Ad hoc On-Demand Distance Vector
ANFC-QGSOR	Adaptive Neural Fuzzy Clustering-Quantum Glowworm Swarm Optimization-based Routing
CHN	Continuous Hopfield Network
CHN-OLSR	Continuous Hopfield Network Optimized Link State Routing
D2D	Device-to-Device
DSDV	Destination Sequenced Distance Vector
DSR	Dynamic Source Routing
EECP	Energy-Efficient Clustering Protocol
EECRPSID	Energy-Efficient Cluster-based Routing Protocol for Secure Information Dissemination
GFA	Greedy Forwarding Advanced
GPS	Global Positioning System
HELLO	Hello Message in OLSR Protocol
IoT	Internet of Things
MANETs	Mobile Ad Hoc Networks
MCNR	Multicriteria Node Rank
MCWMPR	Multicriteria Weighted Multipoint Relay
MDOLSR	Modified Dynamic Optimized Link State Routing
MEQSA-OLSRv2	Multipath Energy and QoS-aware Optimized Link State Routing Protocol version 2
MPRs	Multipoint Relays
NS3	Network Simulator 3
NSGA-II	Non-dominated Sorting Genetic Algorithm II
OLSR	Optimized Link State Routing Protocol
OSM	Open Street Map
PDR	Packet Delivery Ratio
PLR	Packet Loss Ratio
QoS	Quality of Service
RBF	Radial Basis Function
RTT	Round-Trip Time
SUMO	Simulation of Urban MObility
TC	Topology Control
UDP	User Datagram Protocol
VANETs	Vehicular Ad Hoc Networks
WMNs	Wireless Mesh Networks
WSNs	Wireless Sensor Networks
ZRP	Zone Routing Protocol

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