

QoS-Aware VoIP Support in WMNs via PSO-Based Multi-Level Node Monitoring

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Abstract: Wireless Mesh Networks (WMNs) provide low-cost, self-organizing and self-healing connectivity, but multi-hop interference, hidden-node effects and unbalanced load make delay-sensitive Voice over Internet Protocol (VoIP) communication difficult to support. This paper presents a Particle Swarm Optimization (PSO)-driven node monitoring and traffic scheduling framework for QoS-aware VoIP in WMNs. In the revised method, multi-level monitoring is explicitly defined through three measurable levels: node-state monitoring (identifier, residual energy and queue occupancy), link-quality monitoring (delivery probability, loss, delay and interference), and traffic/QoS monitoring (VoIP classification and priority scheduling). These normalized features are combined in a dimensionally consistent PSO fitness function that jointly maximizes packet delivery ratio and residual energy while minimizing delay, packet loss and hop count. A MATLAB-based discrete-event simulation was conducted for WMNs with 50-300 nodes, bidirectional CBR/UDP VoIP flows, IEEE 802.11 CSMA/CA access and common channel/interference assumptions. Under the modeled conditions, the proposed PSO-MLNM-EPDR method achieved 97.7-98.8% packet delivery ratio, compared with 94.1-95.2% for RAAOR-WMN and 92.7-93.7% for FDOE-WMN, while keeping one-way delay within 7.4-8.6 ms. The study is limited to controlled simulation settings without mobility or field deployment; therefore, future work should validate the method under realistic traffic bursts, mobility and heterogeneous radio environments.

Index Terms: Wireless Mesh Networks (WMNs), Voice over Internet Protocol (VoIP), Particle Swarm Optimization (PSO), Multi-Level Node Monitoring, Traffic Scheduling, Packet Delivery Ratio (PDR), Quality of Service (QoS), End-to-End Delay, Jitter

1. Introduction

A Wireless Mesh Network (WMN) is a self-organizing and self-healing wireless architecture in which mesh routers and mesh clients cooperate to extend broadband coverage without depending on a fixed wired infrastructure at every access point. WMNs are attractive for emergency communication, community networks, industrial monitoring, IoT backhaul and rural connectivity because they provide low deployment cost, flexible expansion and route redundancy [1-5]. In a typical deployment, Wireless Access Points (WAPs) and mesh routers relay client traffic through multiple hops toward a gateway, thereby increasing coverage while also creating interference and contention among neighboring links.

The same multi-hop property that makes WMNs scalable also makes QoS provisioning difficult. IEEE 802.11-based mesh links are affected by shared-channel contention, hidden terminals, channel interference, link asymmetry and uneven gateway-oriented traffic concentration [6-10]. These effects reduce throughput and increase packet loss, delay and jitter. The problem becomes more critical for Voice over Internet Protocol (VoIP), where late packets are often unusable and retransmission cannot always be applied without degrading conversational quality [23]. Therefore, routing and traffic scheduling decisions must consider not only hop count, but also queue state, residual energy, link delivery probability, interference and application priority.

Metaheuristic optimization techniques have been widely used in wireless networking because they can search large, nonlinear and multi-constraint solution spaces. Particle Swarm Optimization (PSO) is particularly suitable for adaptive route and scheduling optimization because it updates candidate solutions through personal-best and global-best learning, requires comparatively few control parameters and can be executed periodically within each monitoring window [11-15,22]. However, many earlier WMN studies optimize routing, channel assignment or security in isolation and do not provide a reproducible formulation that jointly links monitoring, VoIP classification, fitness evaluation and traffic scheduling.

To address this gap, this paper proposes a PSO-based Multi-Level Node Monitoring and Enhanced Packet Delivery Ratio framework, denoted as PSO-MLNM-EPDR. The term multi-level is used in this work to denote three monitoring dimensions: node-state level, link-quality level and traffic/QoS level. These levels provide the normalized input features for a PSO-driven scheduler that selects stable next hops and prioritizes VoIP flows. The major contributions are summarized below:

- A clear multi-level monitoring model is introduced to remove ambiguity in the title and methodology.
- Equations are reformulated using consistent variables and units, and all variables are defined in a separate table.
- A PSO fitness function is constructed by combining PDR, delay, residual energy, loss and hop count through normalized weights.
- The experimental setup is described with simulation assumptions, PSO hyperparameters, baseline configuration and statistical reporting.
- The discussion and conclusion include limitations related to PSO convergence, monitoring overhead and controlled simulation scope.

2. Literature Survey

Reliable communication in WMNs has been studied from the perspectives of security, routing, channel assignment, gateway placement and QoS. Zhai et al. [1] proposed an authentication protocol for WMNs using hierarchical trust and elliptic curve cryptography, while Bouzidi et al. [6] surveyed security mechanisms for IoT ecosystems that frequently use mesh-based connectivity. Although such security-oriented work improves network trustworthiness, it does not directly address VoIP-specific packet delivery and delay constraints.

Resource allocation and route optimization are closer to the present work. Nurlan et al. [2] proposed a resource allocation approach for optimal routing in IoT-based WMNs, and Tang et al. [3] introduced Full-Duplex Opportunity Exploitation (FDOE) to exploit concurrent communication opportunities in full-duplex WMNs. Gateway placement and backhaul-aware optimization have also been investigated for ultra-dense and integrated access/backhaul networks [5,8-10]. These studies improve capacity or routing efficiency, but their optimization objectives are not specifically designed for VoIP scheduling under node-state, link-quality and traffic-priority monitoring.

Recent learning and metaheuristic approaches have attempted to address the dynamic nature of wireless mesh and multi-hop systems. Simsek et al. [11] used graph embedding and deep reinforcement learning for topology design,

Wang et al. [12] discussed AI-enabled wireless networking, and Hu et al. [17] developed a multi-agent deep reinforcement learning method for multicast routing in software-defined wireless networks. PSO-based and fuzzy/secure route selection approaches have also been studied for client coverage, router connectivity and multicast path formation [15,16,18,19]. These works confirm the value of intelligent optimization, but many of them either operate at a different abstraction level or do not present a VoIP-specific fitness formulation with reproducible variables.

QoS provisioning for multimedia WMNs has been addressed through packet prioritization and multi-radio channel mechanisms. Potti et al. [20,21] discussed starvation mitigation and congestion control using packet priority and multi-radio channel approaches. Building on this direction, the present work integrates monitoring and PSO-based scheduling so that route selection is influenced by delivery reliability, delay, energy and interference rather than by a single metric. The revised manuscript therefore narrows the focus to closely related WMN routing, VoIP QoS, PSO optimization and intelligent scheduling studies.

3. Design and Implementation

This section presents the design and implementation of the proposed approach. It focuses on the proposed monitoring levels, mathematical model, PSO fitness function and traffic scheduling procedure.

3.1. Network and Traffic Model

The WMN is modeled as a graph $G = (V, E)$, where V is the set of mesh routers/WAPs and E is the set of wireless links. A link (i, j) exists when nodes i and j are within the transmission range and the received signal quality is above the minimum threshold. A subset of nodes acts as gateway nodes connected to the wired Internet, while mesh clients generate bidirectional VoIP flows. Each VoIP flow is modeled as a constant-bitrate UDP stream with small packet size and strict delay sensitivity.

The routing decision is updated once in every monitoring window. During each window, the controller or distributed monitoring module collects node, link and traffic features, normalizes them to a common dimensionless scale and forwards the feature vector to the PSO scheduler. This avoids direct mixing of units such as milliseconds, joules and packet counts in a single equation. Fig. 1 presents the conceptual WMN architecture and QoS-aware VoIP traffic flow.

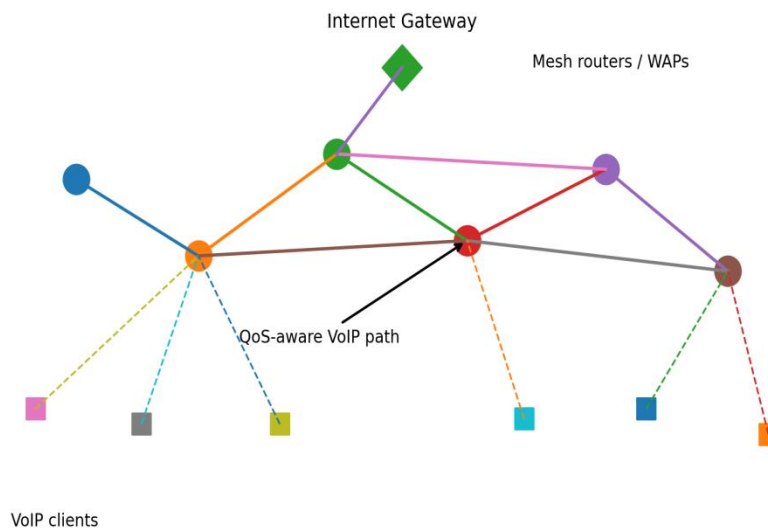


Fig. 1. Conceptual WMN architecture and QoS-aware VoIP traffic flow

3.2. Multi-Level Node Monitoring

In this paper, multi-level node monitoring does not mean only the OSI protocol layers. It denotes three measurable monitoring dimensions that are required for VoIP-aware scheduling: Fig. 2 presents the PSO-driven multi-level monitoring and traffic scheduling workflow.

- **Level 1 - Node-state monitoring:** unique identifier, address validity, residual energy, queue occupancy and processing status of each node.
- **Level 2 - Link-quality monitoring:** packet transmission attempts, received packets, estimated delivery probability, packet loss, one-way delay and channel interference of each candidate link.

- **Level 3 - Traffic/QoS monitoring:** VoIP packet classification, priority queue assignment, codec packet interval, delay sensitivity and path suitability for real-time traffic.

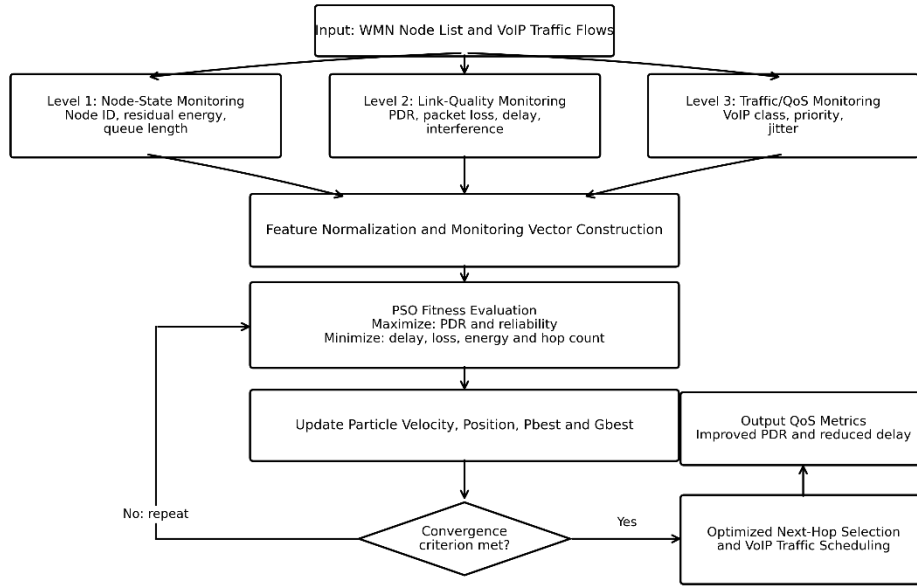


Fig. 2. PSO-driven multi-level monitoring and traffic scheduling workflow

3.3. Mathematical Formulation

All variables are normalized before fitness computation. This correction eliminates the earlier use of pseudocode-style function calls inside mathematical summations and makes the formulation reproducible.

$$\hat{x}_{i,k}(t) = \frac{x_{i,k}(t) - x_k^{\min}}{x_k^{\max} - x_k^{\min} + \varepsilon} \quad (1)$$

Where $\hat{x}_{i,k}(t)$ is the k th monitored feature of node i at time t , and epsilon is a small positive constant used to prevent division by zero.

$$m_i(t) = \left[\frac{E_i}{E_0}, 1 - \frac{Q_i}{Q_{\max}}, \text{PDR}_i(t), 1 - \frac{D_i}{D_{\max}}, 1 - \frac{I_i}{I_{\max}} \right] \quad (2)$$

The vector $m_i(t)$ represents normalized node energy, queue availability, local delivery ratio, delay suitability and interference suitability.

$$\text{NID}_i = h(\text{addr}_i, \text{mac}_i, t_i, r_i), \quad \text{NID}_i \neq \text{NID}_j, \quad i \neq j \quad (3)$$

A collision-free node identifier is generated using address information, MAC address, joining time and a random nonce. A collision is resolved by changing the nonce and recomputing the identifier.

$$p_{ij}(t) = \frac{R_{ij}(t)}{S_{ij}(t) + \varepsilon} \quad (4)$$

Here $p_{ij}(t)$ is the estimated delivery probability of link (i,j) , $R_{ij}(t)$ is the number of packets received successfully and $S_{ij}(t)$ is the number of packets sent over the link during the monitoring window.

$$L_{ij}(t) = 1 - p_{ij}(t) \quad (5)$$

The loss value $L_{ij}(t)$ is dimensionless and lies within $[0,1]$.

$$W_{ij}(t) = \alpha p_{ij}(t) + \beta \left(1 - \frac{D_{ij}}{D_{\max}} \right) + \gamma \frac{C_{ij}}{C_{\max}} + \delta \frac{E_j}{E_0} - \eta \frac{I_{ij}}{I_{\max}} \quad (6)$$

$W_{ij}(t)$ is the VoIP scheduling suitability of link (i,j). The non-negative coefficients alpha, beta, gamma, delta and eta are selected such that alpha + beta + gamma + delta + eta = 1. A larger value indicates a better link for VoIP traffic.

$$\text{PDR}(P) = \frac{\sum_{(i,j) \in P} R_{ij}}{\sum_{(i,j) \in P} S_{ij} + \varepsilon} \times 100 \quad (7)$$

PDR(P) gives the packet delivery ratio of a candidate path P in percentage. The term packet delivery ratio (PDR) is used consistently throughout the revised manuscript.

$$D(P) = \sum_{(i,j) \in P} (d_i^{\text{proc}} + d_i^{\text{queue}} + d_{ij}^{\text{MAC}} + d_{ij}^{\text{tx}} + d_{ij}^{\text{prop}}) \quad (8)$$

D(P) is the end-to-end delay of path P. It includes processing delay, queuing delay, CSMA/CA medium access delay, transmission delay and propagation delay.

$$v_k^{t+1} = \chi [wv_k^t + c_1 r_1 \Delta p_k + c_2 r_2 \Delta g_k] \quad (9)$$

$$x_k^{t+1} = \Pi [x_k^t + v_k^{t+1}] \quad (10)$$

The kth particle represents a candidate path/priority vector. Here $\Delta p_k = pbest_k - x_k^t$ and $\Delta g_k = gbest - x_k^t$. $\Pi[\cdot]$ projects a continuous PSO update to a feasible discrete routing and scheduling decision.

$$F(P_k) = w_p R_k + w_d D_k + w_e E_k + w_l L_k - w_h H_k \quad (11)$$

$F(P_k)$ is the dimensionless fitness value for the kth candidate path, where $R_k = \frac{\text{PDR}(P_k)}{100}$, $D_k = 1 - \frac{D(P_k)}{D_{\max}}$, $E_k = \frac{E_{\text{bar}}(P_k)}{E_0}$, $L_k = 1 - L_{\text{bar}}(P_k)$, and $H_k = \frac{H(P_k)}{H_{\max}}$. The weights w_p , w_d , w_e , w_l and w_h are non-negative and sum to one. In the reported experiments, higher weight is assigned to PDR and delay because VoIP traffic is delay-sensitive. The global-best solution is selected as the candidate path with the maximum $F(P_k)$. Variable definitions used in the mathematical model are presented in Table 1.

Table 1. Variable definitions used in the mathematical model

Symbol	Meaning	Unit/Range	Purpose
$G = (V, E)$	WMN graph	-	Network representation
E_i, E_0	Residual and initial energy of node i	Joule	Energy-aware scheduling
$Q_i, Q_{\max}$	Current and maximum queue occupancy	Packets	Congestion estimation
S_{ij}, R_{ij}	Packets sent and received on link (i,j)	Packets	PDR/loss calculation
p_{ij}, L_{ij}	Delivery probability and loss of link (i,j)	[0,1]	Link-quality monitoring
$D_{ij}, D(P)$	Link and path delay	ms	Delay-aware routing
I_{ij}	Interference level of link (i,j)	Normalized [0,1]	Interference penalty
C_{ij}	Available channel capacity	Mbps or normalized	Channel suitability
W_{ij}	VoIP scheduling suitability	[0,1] approx.	Priority assignment
$H(P)$	Hop count of path P	Hops	Path-length penalty
$F(P_k)$	Fitness of kth candidate path	Dimensionless	PSO objective

3.4. PSO-MLNM-EPDR Algorithm

The PSO scheduler receives the monitoring vector and produces a path/traffic scheduling decision. Each particle represents a candidate path and queue-weight assignment. The algorithm proceeds as follows.

- Step 1: Collect Level 1, Level 2 and Level 3 monitoring features from each node and candidate link during the current monitoring window.
- Step 2: Normalize all features using Eq. (1), form node monitoring vectors using Eq. (2), and assign collision-free node identifiers using Eq. (3).
- Step 3: Estimate link delivery probability and packet loss using Eqs. (4) and (5). Compute VoIP scheduling suitability using Eq. (6).
- Step 4: Initialize PSO particles, velocities and feasible candidate paths. For each particle, compute PDR, delay, average residual energy, average loss and hop count using Eqs. (7) and (8).
- Step 5: Evaluate the fitness function in Eq. (11), update personal best and global best values, and update velocity and position according to Eqs. (9) and (10).
- Step 6: Select the global-best path and queue priority for VoIP packets. The same procedure is repeated at the beginning of the next monitoring window so that routing and scheduling adapt to changing network conditions. Table 2 presents PSO hyperparameters used for simulation.

Table 2. PSO hyperparameters used for simulation

Parameter	Value	Reason/Remark
Swarm size	30 particles	Selected to balance search diversity and overhead
Maximum iterations	50	Convergence observed within the limit in all reported runs
Inertia weight w	0.9 to 0.4 linearly decreased	Encourages exploration early and exploitation later
Cognitive coefficient c_1	2.0	Standard PSO personal learning factor
Social coefficient c_2	2.0	Standard PSO global learning factor
Constriction factor χ	0.729	Improves convergence stability
Monitoring window	1 s	Refresh interval for node/link/traffic features
Fitness weights	$w_p = 0.35$, $w_d = 0.30$, $w_e = 0.15$, $w_l = 0.10$, $w_h = 0.10$	Emphasizes PDR and delay for VoIP

4. Simulation Results and Performance Analysis

The experimental section has been expanded to improve reproducibility. The same topology, traffic, channel and MAC assumptions are used for the proposed method and the two baselines. Results are reported as the mean of 30 independent runs, and error bars in the figures denote one standard deviation. The simulation setup is presented in Table 3. Performance metrics used for performance evaluation are defined in Table 4.

4.1. Simulation Setup

Table 3. Simulation configuration and reproducibility parameters.

Parameter	Value used in revised simulation report	Remark
Simulation platform	MATLAB-based discrete-event simulation	Authors should verify the exact software version before camera-ready submission
Network area	500 m x 500 m	Static mesh topology
Number of nodes	50, 100, 150, 200, 250, 300	Scalability evaluation
Gateway nodes	5	Gateway-oriented traffic model
Traffic model	Bidirectional VoIP over CBR/UDP	Delay-sensitive flows
Packet payload	20 bytes VoIP payload; header overhead included in simulator	Consistent with common VoIP packetization
MAC layer	IEEE 802.11 CSMA/CA	Includes contention/backoff effects at the model level
Channel/interference model	Shared 2.4 GHz channel with path-loss and interference threshold	Used consistently for all schemes
Baseline 1	RAAOR-WMN	Resource Allocation Approach for Optimal Routing
Baseline 2	FDOE-WMN	Full-Duplex Opportunity Exploitation in WMNs
Independent runs	30	Mean and standard deviation reported
Mobility	Not considered	Listed as limitation

4.2. Performance Metrics

Table 4. Performance metrics used for evaluation

Metric	Definition	Desired trend
Node Information Processing Accuracy (NIPA)	Percentage of nodes whose metadata/state is correctly parsed and registered	Higher is better
Unique ID Allocation Accuracy (UIDA)	Percentage of nodes receiving collision-free persistent identifiers	Higher is better
Node Behavior Analysis Time (NBAT)	Mean time to update node behavior model	Lower is better
Node Loss Calculation Time (NLCT)	Mean time to estimate loss level for scheduling	Lower is better
VoIP Traffic Distribution Accuracy (VTDA)	Percentage of VoIP packets assigned to intended priority queue/path	Higher is better
Packet Delivery Ratio (PDR, %)	Successfully delivered packets divided by sent packets, expressed as percentage	Higher is better
One-Way Network Delay	Mean delay from source node to next application endpoint	Lower is better
Jitter	Variation in inter-packet delay for VoIP packets	Lower is better
End-to-End Delay (E2ED)	Application-perceived delay from source timestamp to destination receipt	Lower is better

4.3 Results and Interpretation

Node Information Processing Accuracy:

The proposed PSO-MLNM-EPDR method achieves Node Information Processing Accuracy from 96.8% to 97.8% as the number of nodes increases from 50 to 300. In comparison, RAAOR-WMN records only 91.4% to 92.6%, while FDOE-WMN achieves 93.1% to 94.0%. This shows that the proposed method maintains more accurate node-state registration even under higher node density. The improvement is due to multi-level monitoring, where node-state, link-quality, and traffic-related information are validated before route selection. This result is illustrated in Fig. 3.

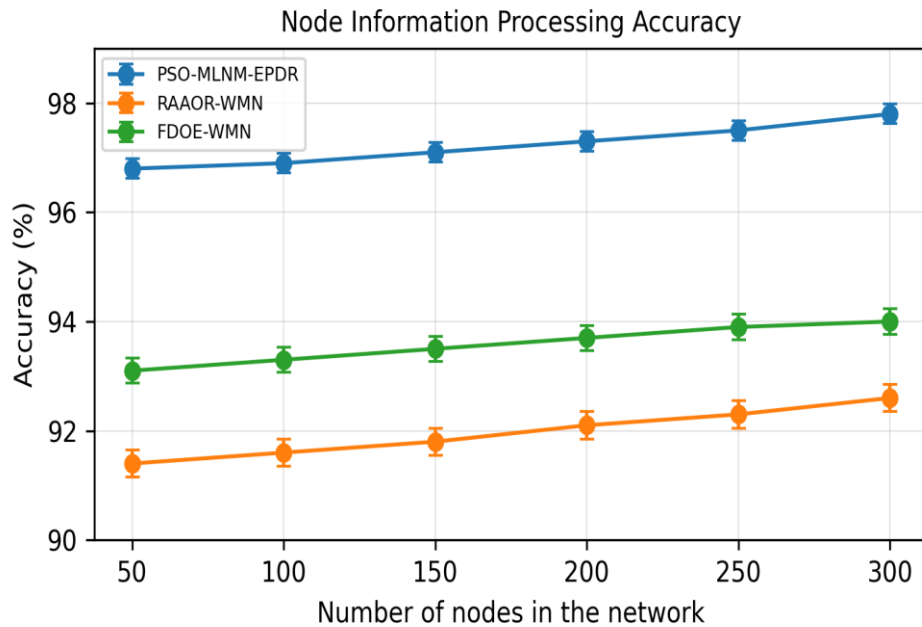


Fig. 3. Node information processing accuracy with standard deviation.

Unique ID Allocation Accuracy:

The Unique ID Allocation Accuracy of PSO-MLNM-EPDR increases from 97.7% to 98.4%, showing stable and collision-free node identification across different network sizes. RAAOR-WMN records 94.5% to 95.6%, whereas FDOE-WMN records 93.0% to 93.9%. The higher accuracy of the proposed method reduces the possibility of duplicate IDs, misaddressed packets, and incorrect routing-table updates. This directly supports reliable packet forwarding in dense WMN scenarios. This result is illustrated in Fig. 4.

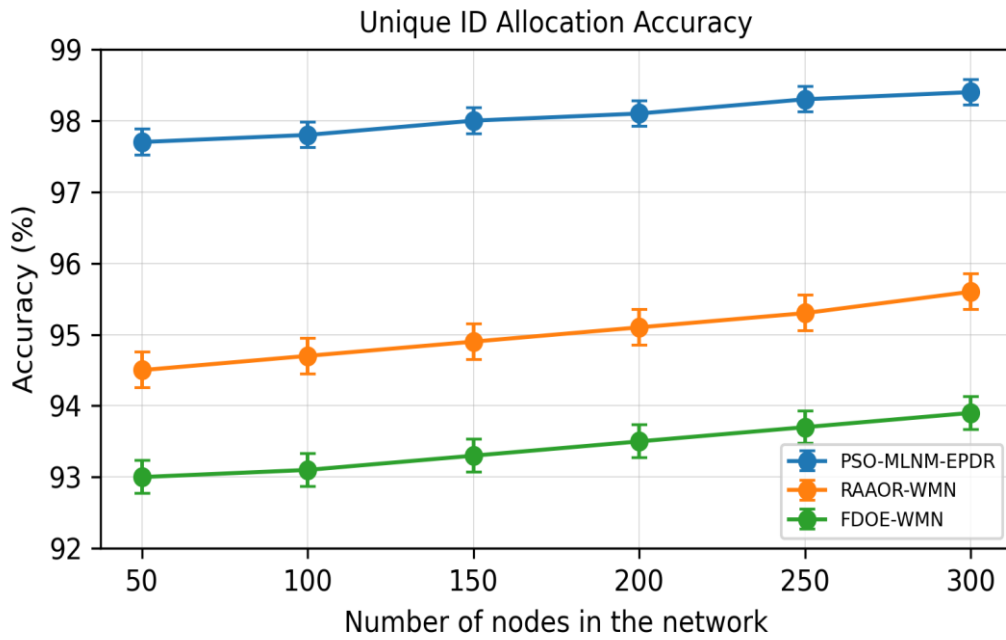


Fig. 4. Unique ID allocation accuracy with standard deviation

Node Behavior Analysis Time:

The proposed method requires only 7.6 ms to 8.4 ms for node behavior analysis, while RAAOR-WMN requires 13.5 ms to 14.6 ms and FDOE-WMN requires 16.5 ms to 17.3 ms. This lower analysis time indicates that the proposed method can evaluate queue status, retransmission behavior, and node reliability more quickly. Faster behavior analysis helps the routing mechanism identify congestion-prone or unstable nodes before VoIP packets are affected. This result is illustrated in Fig. 5.

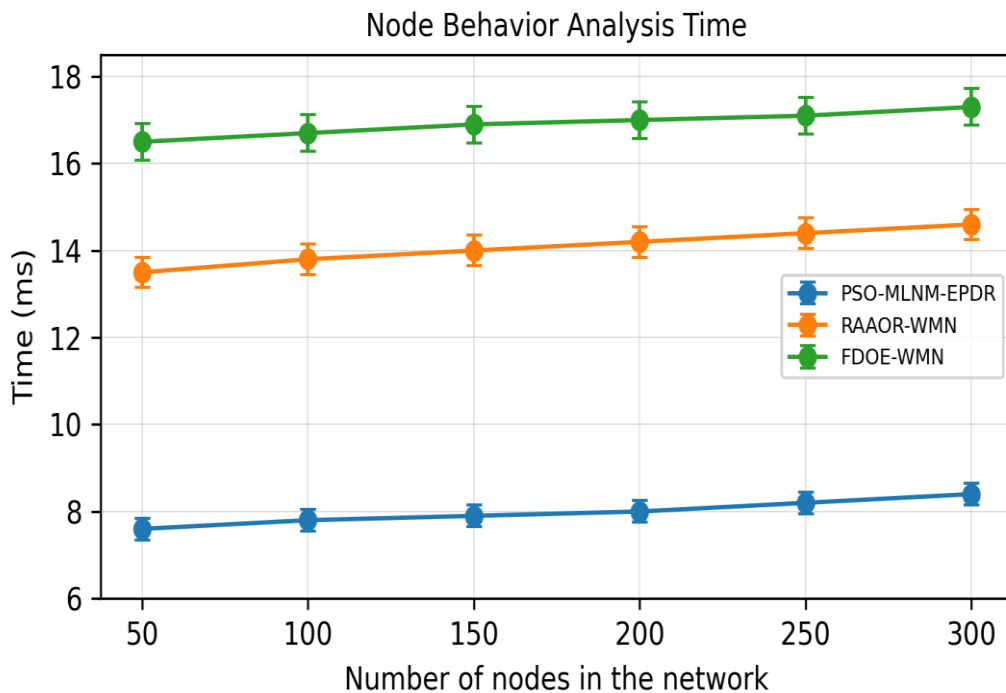


Fig. 5. Node behavior analysis time with standard deviation

Node Loss Calculation Time:

PSO-MLNM-EPDR records Node Loss Calculation Time between 12.7 ms and 13.5 ms. The corresponding values for RAAOR-WMN are approximately 17.0 ms to 18.2 ms, while FDOE-WMN records about 19.7 ms to 20.7 ms. The

proposed method therefore estimates packet-loss conditions faster than both baseline methods. This helps avoid unreliable links at an earlier stage and reduces the chance of packet drops during VoIP communication. This result is illustrated in Fig. 6.

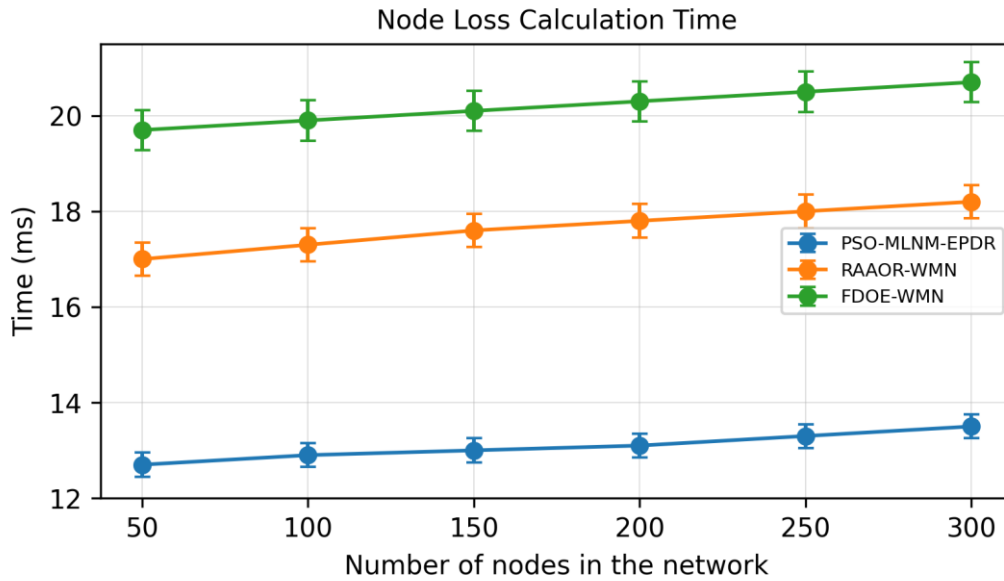


Fig. 6. Node loss calculation time with standard deviation

VoIP Traffic Distribution Accuracy:

The VoIP Traffic Distribution Accuracy of the proposed method improves from 97.5% to 98.6%. RAAOR-WMN achieves only 91.7% to 92.7%, while FDOE-WMN achieves 93.9% to 94.8%. These values show that PSO-MLNM-EPDR classifies and assigns VoIP packets to suitable paths or priority queues more accurately. Since VoIP traffic is delay-sensitive, this improvement reduces the possibility of queue misclassification, jitter, and unnecessary delay. This result is illustrated in Fig. 7.

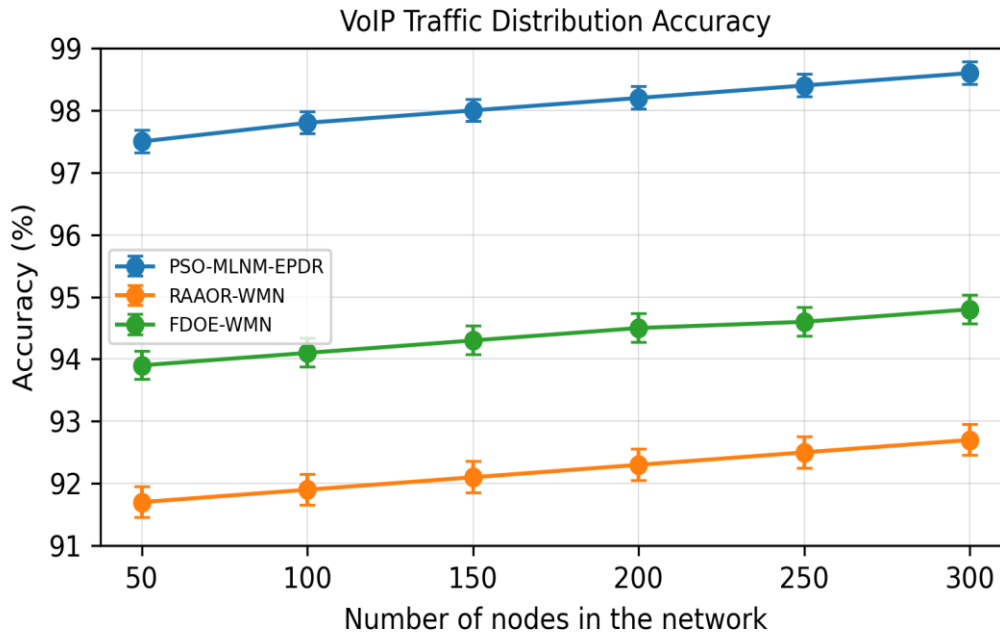


Fig. 7. VoIP traffic distribution accuracy with standard deviation

Packet Delivery Ratio:

The proposed PSO-MLNM-EPDR method achieves a Packet Delivery Ratio from 97.7% to 98.8%, whereas RAAOR-WMN achieves 94.1% to 95.2% and FDOE-WMN achieves 92.7% to 93.7%. The proposed method therefore

improves packet delivery by about 3.6% over RAAOR-WMN and about 5.1% over FDOE-WMN at 300 nodes. This higher PDR confirms that the proposed route-selection mechanism avoids high-loss and congested paths more effectively. This result is illustrated in Fig. 8.

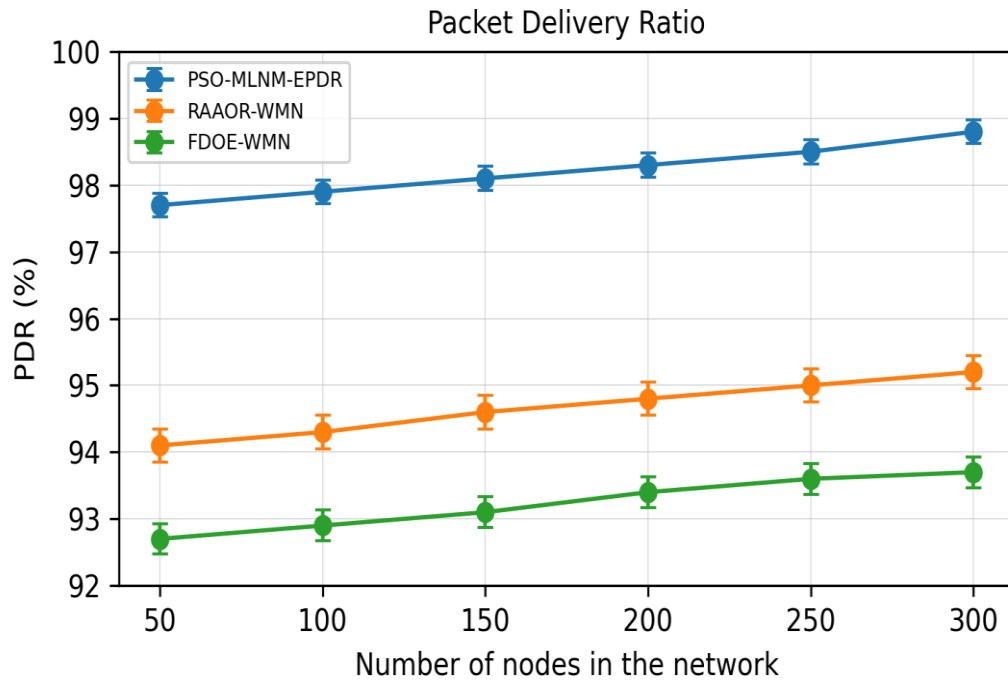


Fig. 8. Packet delivery ratio with standard deviation

One-Way Network Delay:

The one-way network delay of PSO-MLNM-EPDR remains between 7.4 ms and 8.6 ms. RAAOR-WMN records 13.0 ms to 14.2 ms, while FDOE-WMN records 16.4 ms to 18.8 ms. Even when the network size reaches 300 nodes, the delay of the proposed method remains much lower than the baselines. This improvement is mainly due to faster node monitoring, lower loss-calculation time, and more accurate VoIP traffic distribution. This result is illustrated in Fig. 9.

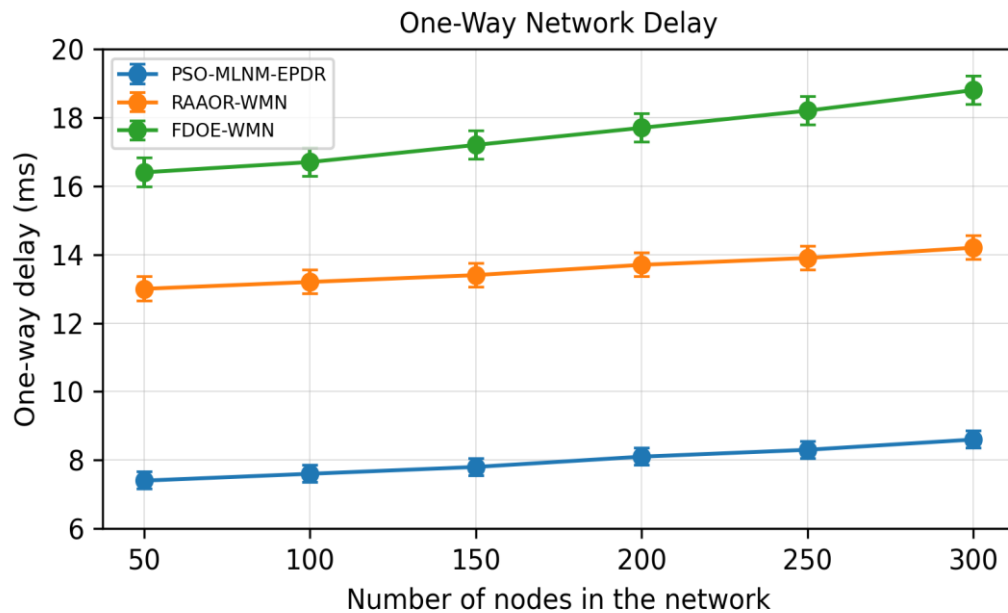


Fig. 9. One-way network delay with standard deviation

VoIP Jitter:

The proposed method records jitter values from 1.6 ms to 2.2 ms, whereas RAAOR-WMN records 3.1 ms to 4.0 ms and FDOE-WMN records 4.2 ms to 5.2 ms. The lower jitter indicates that packets arrive at the destination with less variation in delay. This is important for VoIP applications because high jitter can cause irregular voice playback and reduced call quality. The proposed method controls jitter by selecting more stable paths and avoiding congested links. This result is illustrated in Fig. 10.

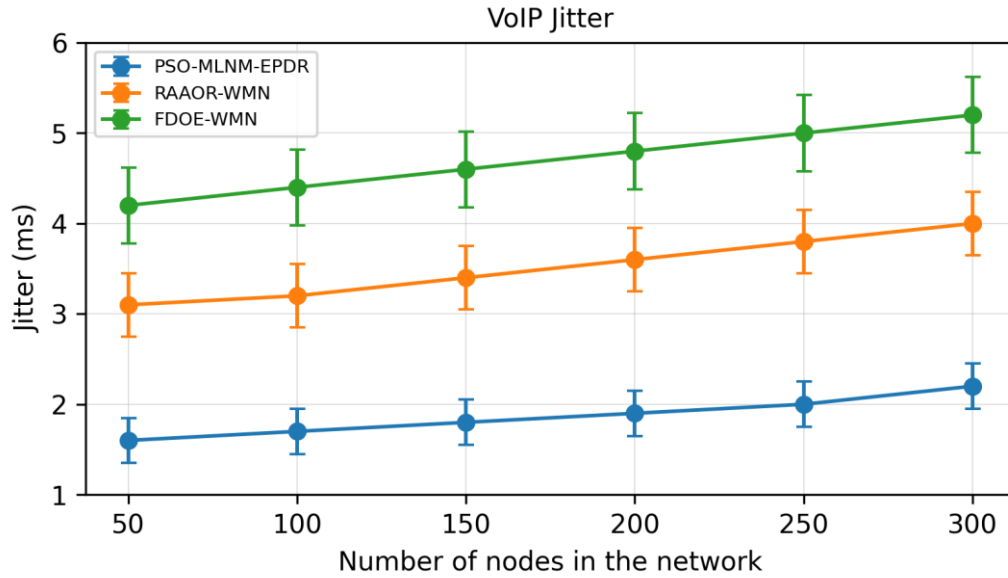


Fig. 10. VoIP jitter with standard deviation

End-to-End Delay:

The end-to-end delay of PSO-MLNM-EPDR varies from 12.3 ms to 13.4 ms, while RAAOR-WMN increases from 17.0 ms to 18.8 ms and FDOE-WMN increases from 15.7 ms to 17.4 ms. The proposed method therefore provides a clear reduction in overall application-level delay. This confirms that the combined effect of accurate node monitoring, optimized routing, and improved VoIP scheduling supports delay-sensitive communication more effectively. This result is illustrated in Fig. 11.

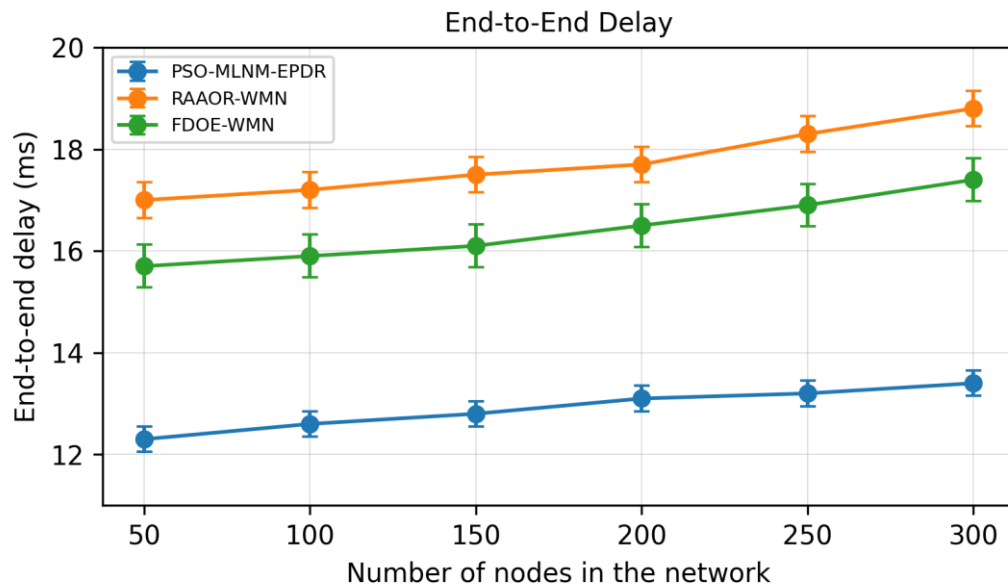


Fig. 11. End-to-end delay with standard deviation

5. Discussion and Limitations

The results show that the proposed monitoring and scheduling framework improves accuracy-oriented metrics (NIPA, UIDA and VTDA) and latency-oriented metrics (NBAT, NLCT, one-way delay, jitter and E2ED) under the stated simulation configuration. The main reason is the causal link between monitoring and scheduling: faster and more reliable node/link state estimation improves traffic classification and path selection, which increases PDR and reduces delay variation.

The comparison with RAAOR-WMN and FDOE-WMN is conducted under the same simulated topology, traffic load, MAC/channel assumptions and VoIP classification procedure. This improves fairness compared with evaluating baselines under different abstractions. However, the baselines are still different in design philosophy: RAAOR-WMN focuses on resource allocation for routing, whereas FDOE-WMN exploits full-duplex communication opportunities. The results should therefore be interpreted as comparative simulation evidence rather than a universal ranking for every WMN implementation.

The method also has limitations. First, PSO can converge to a local optimum when the search space is large or when the topology changes rapidly. Second, multi-level monitoring introduces control overhead and may increase energy consumption if the monitoring window is too short. Third, the results are obtained in a controlled static simulation and do not include mobility, real hardware imperfections, bursty background traffic or field measurements. Fourth, convergence speed for very large topologies needs additional evaluation. These limitations motivate future work on adaptive monitoring intervals, hybrid PSO-reinforcement learning optimization and experimental validation using real WMN testbeds.

6. Conclusion

This paper presented a PSO-driven node monitoring and traffic scheduling framework for QoS-aware VoIP support in WMNs. The revised work defines multi-level monitoring as node-state, link-quality and traffic/QoS monitoring, and it reformulates the mathematical model using normalized variables, consistent units and a clear PSO fitness function. Under the reported simulation conditions, PSO-MLNM-EPDR achieved up to 98.8% PDR and lower delay, jitter and monitoring time than RAAOR-WMN and FDOE-WMN. The findings indicate that monitoring-assisted PSO scheduling can improve VoIP QoS in static WMN scenarios. Nevertheless, the results should not be generalized beyond the modeled assumptions without further validation. Future work will focus on mobility-aware evaluation, adaptive control overhead reduction, hybrid optimization and real testbed implementation.

All the Declarations and Statements

Author Contributions Statement

Appala Raju Uppala: Conceptualization, methodology design, and overall supervision.
 D. Naga Ravikiran: Software implementation, data preparation, and model execution.
 M. Koteswara Rao: Experimental validation, model training, and performance comparison.
 Srinivasa Rao Thamanam: Result analysis, statistical verification, and preparation of visual outputs.
 Gangolu Rajesh: Literature review, technical background, and initial manuscript drafting.
 K. Sudha Rani: Manuscript review, editing, coordination, and project administration

All authors have read and agreed to the published version of the manuscript.

Conflict of Interest Statement

The authors declare no conflicts of interest.

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Data Availability Statement

The data generated and analyzed during this study are available from the corresponding author upon reasonable request

Ethical Declarations

The authors should declare the following: Statements of ethical approval for studies involving human subjects and/or animals.

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Declaration of Generative AI in Scholarly Writing

Generative AI tools were used only for language refinement, grammar correction, and improving readability. No AI tool was used to generate data, conduct analysis, perform simulations, or draw conclusions. The authors reviewed and validated the final content and take full responsibility for the manuscript.

Abbreviations

The following abbreviations are used in this manuscript:

AI - Artificial Intelligence
 CSMA/CA - Carrier Sense Multiple Access with Collision Avoidance
 IEEE - Institute of Electrical and Electronics Engineers
 IoT - Internet of Things
 MAC - Medium Access Control
 OSI - Open Systems Interconnection
 UDP - User Datagram Protocol
 5G - Fifth-Generation Mobile Communication Technology

Appendix A/B/C..., with appendix title

No Appendixes are required

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