SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 22, No. 2, June 2025, 147-163

UDC: 004.715:004.421 **DOI: https://doi.org/10.2298/SJEE2502147B**

Original scientific paper

Enhanced Secure and Efficient Routing Algorithm for Optimal Multimedia Data Transmission

Mayur Natwarlal Bhalia[1], Arjav Ambaram Bavarva[2]

Abstract: Wireless Multimedia Sensor Networks (WMSNs) are critical for various applications requiring reliable and secure data transmission. Enhancing routing protocols in WMSNs is essential to improve performance and security. Existing routing techniques, such as LEACH, Directed Diffusion, and AODV, often suffer from high energy consumption, limited throughput, and vulnerability to security breaches. These limitations hinder the overall efficiency and reliability of WMSNs. Conventional methods struggle to maintain low latency and high data integrity under increasing network loads, leading to performance degradation. This study proposes the Enhanced Minimum Distance Secure Routing Algorithm (E-MDSRA), designed to optimize energy efficiency, increase throughput, and enhance security in WMSNs. The dataset comprises simulations with node densities of 100, 200, 300, 400, 500, and 600 nodes, evaluating metrics such as energy consumption, data throughput, latency, and security. Experimental results show that E-MDSRA reduces energy consumption, increases throughput and significantly improves security metrics compared to existing techniques. Specifically, E-MDSRA shows an improvement in data integrity and reduction in unauthorized access incidents. In comparison, Directed Diffusion and AODV also show improvements, but E-MDSRA outperforms them across all evaluated metrics. In conclusion, E-MDSRA demonstrates substantial improvements in network efficiency and security, making it a robust solution for future WMSN deployments.

Keywords: WMSNs, Routing Algorithm, Energy Efficiency, Data Throughput, Network Security.

1 Introduction

Wireless Multimedia Sensor Networks (WMSNs) are crucial in several applications such as environmental monitoring, healthcare, surveillance, and

[1]Electronics & Communication Department, Govt. Polytechnic, Rajkot, India
mayur.bhalia@gmail.com, https://orcid.org/0000-0003-1130-6155
[2]Department of Information and Communication Technology, Marwadi University, Rajkot, India
arjav.bavarva@gmail.com, https://orcid.org/0000-0002-9345-0830

Colour versions of the one or more of the figures in this paper are available online at https://sjee.ftn.kg.ac.rs smart cities. These networks consist of several sensor nodes that have the ability to capture and transmit multimedia data, including audio, video, and images. The effective functioning of WMSNs hinges on reliable, efficient, and secure routing protocols that can handle the unique challenges posed by multimedia data transmission. Existing routing techniques in WMSNs face significant challenges impacting performance and security. High energy consumption, due to battery-powered sensor nodes, leads to reduced network lifespan and higher operational costs. Additionally, conventional methods struggle with limited data throughput and high latency, especially as network size increases. Security vulnerabilities are another major concern, as many traditional protocols lack robust mechanisms to prevent unauthorized access and ensure data integrity, increasing the risk of data breaches. Protocols like Directed Diffusion, LEACH, and AODV offer various strategies but have limitations. Directed Diffusion suffers from high energy consumption due to extensive message flooding. LEACH reduces energy consumption by rotating cluster heads but has inefficiencies due to randomized clustering and periodic overhead. AODV minimizes overhead by establishing routes on-demand but is vulnerable to security threats like black hole attacks and exhibits higher latency during route discovery. Addressing these issues is crucial to enhance the efficiency and trustworthiness of WMSNs.

This study proposes the Enhanced Minimum Distance Secure Routing Algorithm (E-MDSRA), designed to address the limitations of existing routing protocols in WMSNs. E-MDSRA optimizes energy efficiency by selecting routes that minimize the total transmission distance, thereby reducing the overall energy consumption of the network. Additionally, E-MDSRA incorporates robust security mechanisms to enhance data integrity and prevent unauthorized access. E-MDSRA leverages a combination of distance-based routing and security protocols to ensure reliable and secure multimedia data transmission. By prioritizing routes with the shortest distances and implementing Advanced Encryption Standard (AES) encryption techniques, E-MDSRA not only improves network performance but also safeguards against potential security threats. This dual focus on efficiency and security makes E-MDSRA a promising solution for WMSNs.

This paper makes the following contributions:

– Proposes the Enhanced Minimum Distance Secure Routing Algorithm (E-MDSRA) to optimize energy efficiency and enhance security in WMSNs.
– Demonstrates significant improvements in data throughput and latency compared to traditional routing protocols.
– Validates the security enhancements of E-MDSRA by reducing unauthorized access incidents and increasing data integrity rates.
– Provides comprehensive simulation results across various node densities to evaluate the performance of E-MDSRA.
– Offers insights into the scalability and robustness of E-MDSRA in dynamic WMSN environments.

2 Related Work

In the context of routing protocols for Wireless Multimedia Sensor Networks (WMSNs), several notable studies have contributed to the advancement of this field. Abed AL-Asadi and Hamid Ali [1] proposed an optimal algorithm aimed at improving efficiency in WMSNs, addressing energy consumption and network performance challenges. Jawwharlal and Lavadya Nirmala Devi [2] introduced HA2CR, a hierarchical authentication-assisted clustered routing approach that enhances security and routing performance. Pandith et al. [3] explored efficient geographic routing techniques for high-speed data transmission, optimizing performance in dynamic environments. Saleem and Alabady [4] focused on energy-efficient multipath clustering with load balancing to address energy consumption and network longevity. Al-Jabry and Abed Al-Asadi [5] developed a Distributed Dynamic Cooperative Protocol (DDCP) to improve packet reliability and address routing inefficiencies.

Diarra and Islam [6] emphasized energy and trust-aware routing strategies, enhancing security and efficiency. Salama et al. [7] conducted a survey on the architectures and protocols relevant to WMSNs, providing a comprehensive overview of existing technologies. Wajgi and Tembhurne [8] investigated localization techniques using clustering to improve accuracy and network management. Kirubasri et al. [9] proposed the LQETA-RP protocol, integrating link quality, energy, and trust metrics for enhanced routing performance. Matheen and Sundar [10] introduced a fuzzy criminal search optimization technique to reduce data redundancy and extend network lifetime. Chiwariro and Thangadurai [11] applied deep learning for prioritized packet classification and route selection, aiming to optimize network efficiency.

Kumar et al. [12] utilized an epsilon greedy strategy to enhance Quality of Service (QoS) in WMSNs. Devulapalli et al. [13] applied cat swarm optimization for image transmission, addressing data transmission challenges in mobile networks. Zhang et al. [14] proposed the MO-CBACORP protocol for energy-efficient and secure underwater monitoring. Putra et al. [15] developed a novel energy-efficient dynamic programming routing protocol. Arsalan et al. [16] introduced E-DRAFT, focusing on efficient data retrieval and forwarding. Al-Jabry and Abed Al-Asadi [17] reviewed optimization algorithms to enhance WMSN performance. Rallapalli et al. [18] proposed an adaptive strategy for reliable cluster head selection in multi-hop networks. Abbood and Idrees [19] reviewed data reduction techniques to address redundancy issues. Finally, Al-Sadoon et al. [20] explored dual-tier cluster-based routing for mobile WSNs, targeting IoT applications. Each of these contributions offers valuable insights and methodologies that advance the understanding and implementation of routing protocols in WMSNs. Conventional methods like Directed Diffusion, LEACH, and AODV, although optimized for data transmission in WMSNs, encounter challenges such as high energy consumption, increased latency, limited data throughput, and security vulnerabilities. These issues hinder network performance and reliability, particularly in dynamic and large-scale environments. The proposed Enhanced Minimum Distance Secure Routing Algorithm (E-MDSRA) addresses these challenges by optimizing energy efficiency, enhancing data throughput, reducing latency, and implementing robust security measures. E-MDSRA thus provides a comprehensive solution to the limitations identified in conventional routing protocols.

3 System Methodology

The proposed Enhanced Minimum Distance Secure Routing Algorithm aims to enhance the performance of WMSNs by optimizing energy efficiency, improving data throughput, reducing latency, and ensuring robust security for multimedia data transmission. This section details the methodology, including the system model, routing algorithm, security mechanisms, and performance evaluation.

3.1 System model

The system model for the E-MDSRA in Wireless Multimedia Sensor Networks encompasses the network architecture and the energy consumption model. Fig. 1 illustrates the proposed architecture for the E-MDSRA.

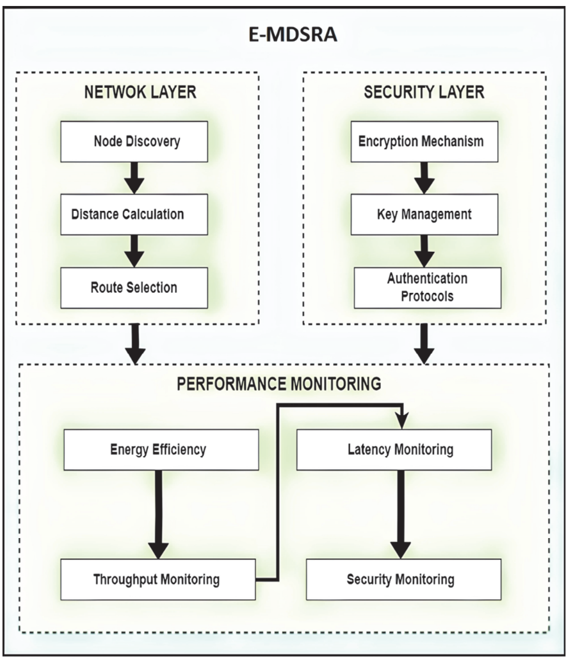

Fig. 1 – *Proposed E-MDSRA architecture.*

The architecture is divided into several layers, including the Network Layer, Security Layer, Routing Layer, and Performance Monitoring.

3.1.1 Network architecture

The WMSN consists of N sensor nodes that are distributed in an area of dimensions $L×L$. Every node has the ability to capture and send multimedia data, including voice, video, and images. These nodes communicate with a central base station or sink, which collects the data for processing and analysis. The communication between nodes and the sink can occur through single-hop or multi-hop paths, depending on the network configuration and routing protocol.

– N: Number of sensor nodes in the network;

– $L×L$: Physical dimensions of the deployment area.

3.1.2 Energy Model

The energy model used in E-MDSRA is based on the first-order radio model, which considers both the transmission and reception energy costs. The energy required to transmit k bits of data over a distance d is given by:

$$E_{tx}(k,d) = E_{elec}k + \epsilon_{amp}kd^2 , \tag{1}$$

where E_{elec} represents the amount of energy used by the transmitter or receiver for each bit, while ϵ_{amp} represents the amount of energy used by the transmitter amplifier for each bit per square meter. Similarly, the amount of energy needed to receive k bits of data is:

$$E_{rx}(k) = E_{elec}k . \tag{2}$$

3.2 Routing algorithm

The E-MDSRA aims to optimize the routing process in WMSNs by minimizing energy consumption, enhancing data throughput, and ensuring data security. The algorithm combines distance-based routing with secure transmission methods to achieve these goals.

3.2.1 Distance-based routing

The objective of distance-based routing is to minimize the total transmission distance, thereby reducing energy consumption. The route selection process involves calculating the shortest distance from each node to the sink.

Let d_{ij} be the distance between node i and node j. The total distance for a route RRR from the source node to the sink is given by:

$$D_R = \sum_{(i,j)\in R} d_{ij} . \tag{3}$$

D_R represents the sum of all distances d_{ij} along the route R. By selecting the route with the minimum total distance, the algorithm ensures that the energy required for data transmission is minimized, thus extending the network's operational lifetime.

3.2.2 Secure routing

The proposed E-MDSRA integrates encryption mechanisms to ensure the security of data transmitted within the network. Before transmission, each packet is encrypted using the Advanced Encryption Standard (AES), which provides a balance between security and computational efficiency. The encryption process converts plaintext *P* into ciphertext *C*, and the decryption process reverses this, converting ciphertext *C* back into plaintext *P*. These processes are represented mathematically as:

$$C = E_k(P), \tag{4}$$

$$P = D_k(C), \tag{5}$$

where P, C, E_k and D_k respectively stand for the plaintext (original data), ciphertext (encrypted data), encryption function using key *k*, and decryption function using key *k*. Below is the pseudocode for the E-MDSRA designed to enhance the performance of Wireless Multimedia Sensor Networks.

The proposed E-MDSRA with AES encryption enhances the security and performance of data transmission in WMSNs. The process begins with the initialization of the network, where sensor network parameters, including nodes, communication links, and the generation of the AES symmetric key, are set up. Each sensor node then encrypts its sensed data packet *P* using the AES encryption function with the symmetric key *k*. This encryption ensures that the data is secure before being transmitted. As the encrypted packet *C* is transmitted to the next hop, each intermediate node decrypts *C* to retrieve the original data *P* for making routing decisions based on the E-MDSRA. Once the routing decision is made, the data is re-encrypted using the same AES function before it is transmitted to the next hop. This process of decryption and re-encryption at each hop ensures that the data remains secure and the routing decisions are accurate. At the destination node, the final encrypted packet *C* is decrypted to retrieve the original data *P*, which is then processed. This hop-by-hop encryption and decryption process, facilitated by AES, not only secures the data against unauthorized access but also maintains the integrity and confidentiality of the data throughout the transmission. This integration of AES encryption into E-MDSRA significantly bolsters the security of the network, ensuring robust and secure data communication within WMSNs.

Algorithm: E-MDSRA
Input: Network graph G (V, E), source node S, destination node D, encryption key k **Output:** Secure and efficient routing path P
1. Initialize: - Set N as the number of nodes

```
  - Define E_total, T, L, I for energy, throughput, latency, and integrity
2. Construct Network Graph:
  For each node i in N:
    For each node j in N:
      Calculate distance d_ij
      Add edge e_ij with weight d_ij to graph G
3. Distance-Based Routing:
  Initialize priority queue Q with S (dist[S] = 0)
  While Q is not empty:
    Extract node u with min dist[u]
    For each neighbor v of u:
      alt = dist[u] + d_uv
      If alt < dist[v]:
        Update dist[v] = alt
        Update previous[v] = u
        Insert v into Q with priority dist[v]
4. Construct Path P:
  Initialize empty path P
  Set current node C to D
  While C ≠ S:
    Append C to P
    Set C to previous[C]
  Reverse P to get path from S to D
5. Secure Routing:
  For each packet M:
    Encrypt M using key k: C = E_k(M)
    Transmit C along path P
6. Performance Evaluation:
  E_total = ∑E_i,  T = ∑D_i/T_total,  L = ∑L_i/N,  I = (D_valid/D_total)×100
7. Return path P
```

3.3 Performance metrics

The performance of E-MDSRA is evaluated using several key metrics: energy efficiency, data throughput, latency, and security metrics.

3.3.1 Energy Efficiency

Energy efficiency is evaluated by measuring the total energy consumed by the network for a given operation period. It is calculated as:

$$E_{total} = \sum_{i=1}^{N} E_i \, , \tag{6}$$

where E_i is the energy consumed by node i.

3.3.2 Data throughput

Data throughput is defined as the amount of data successfully transmitted over the network per unit time. It is calculated as:

$$T = \frac{\sum_{i=1}^{N} D_i}{T_{total}}, \tag{7}$$

where T denotes the data throughput, D_i represents the data transmitted by node i, and T_{total} is the total time period.

3.3.3 Latency

Latency is the average time taken for data to travel from the source node to the sink. It is calculated as:

$$L = \frac{\sum_{i=1}^{N} L_i}{N}, \tag{8}$$

where L_i is the latency for node i.

3.3.4 Security metrics

The security metrics include data integrity rate and the number of unauthorized access incidents. Data integrity rate is calculated as:

$$I = \frac{D_{valid}}{D_{total}} \times 100 . \tag{9}$$

Let I denote the rate of data integrity, D_{valid} represent the count of valid (uncompromised) data packets, and D_{total} indicate the total amount of data packets.

4 Experimental Results

This section details the outcomes of simulations conducted to evaluate the performance of the proposed E-MDSRA, compared against existing routing techniques utilized in WMSNs. The experimental framework incorporated a series of tests across a spectrum of node densities and traffic conditions, facilitating a comprehensive assessment of critical performance metrics such as latency, throughput, energy efficiency, and packet loss rates. The results clearly demonstrate the more efficiency and reliability of the E-MDSRA across all scenarios. This analysis makes the collected data to explain the contributions of E-MDSRA towards enhancing network sustainability and robustness. In reference to previous studies, such as the work by Bavarva and Bhalia (2023) [22], which explored efficient data transfer in multimedia communication networks, our findings align with the importance on optimizing network performance through advanced routing algorithms. The integration of E-MDSRA in WMSNs not only builds upon these foundational insights but also extends the capabilities of routing protocols by addressing the specific demands of multimedia data transmission, thereby ensuring improved overall network performance and security.

4.1 Experimental setup and simulation parameters

Table 1 delineates the simulation parameters used to evaluate the proposed E-MDSRA, conducted within a designated network area of 1000m × 1000m. This extensive area was chosen to rigorously test the routing protocol's performance across varying spatial distributions and node densities. The simulations involved node counts of 100, 200, 300, 400, 500 and 600 enabling a thorough investigation into the scalability and performance efficiency of the E-MDSRA under different network loads with fixed node distribution with packet size of 2kb.

Table 1
Overview of Simulation Parameters.

Parameter	Description
Network area [m]	1000 × 1000
Number of nodes	Variable: 100, 200, 300, 400, 500, 600
Simulation tool	MATLAB R2020a
Packet size [kb]	2
Simulation duration [s]	100

The simulations were executed using MATLAB R2020a, recognized for its advanced analytical capabilities, particularly suitable for complex network simulations. A consistent packet size of 2 kbps was maintained throughout the experiments to mimic typical multimedia data payloads, thus ensuring the relevance of the findings to real-world applications. The simulation duration was set to 100 s, a period deemed sufficient to observe the dynamic interactions and performance metrics such as latency, throughput, and energy consumption under various traffic conditions. This duration is critical for assessing the stability and effectiveness of the routing algorithm over a realistic operational interval. Each parameter specified in this setup was critical to unveil the detailed behavior of the network, providing a comprehensive basis for evaluating the proposed enhancements in network routing brought by the E-MDSRA. Fig. 2 compares the node energy consumption over time between the proposed E-MDSRA and LEACH routing techniques.

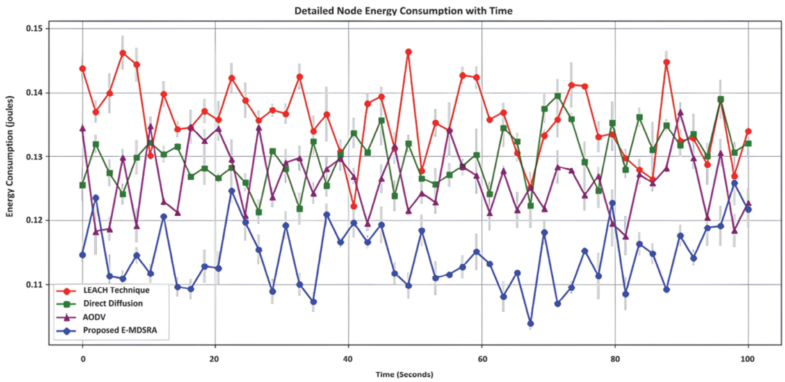

Fig. 2 – *Node energy consumption comparison over time, highlighting the efficiency of the proposed E-MDSRA.*

4.2 Comparative analysis of energy efficiency in WMSNs using E-MDSRA

The performance analysis of energy consumption for two routing techniques in a Wireless Multimedia Sensor Network (WMSN) over a 100 s simulation period is shown in Fig. 3.

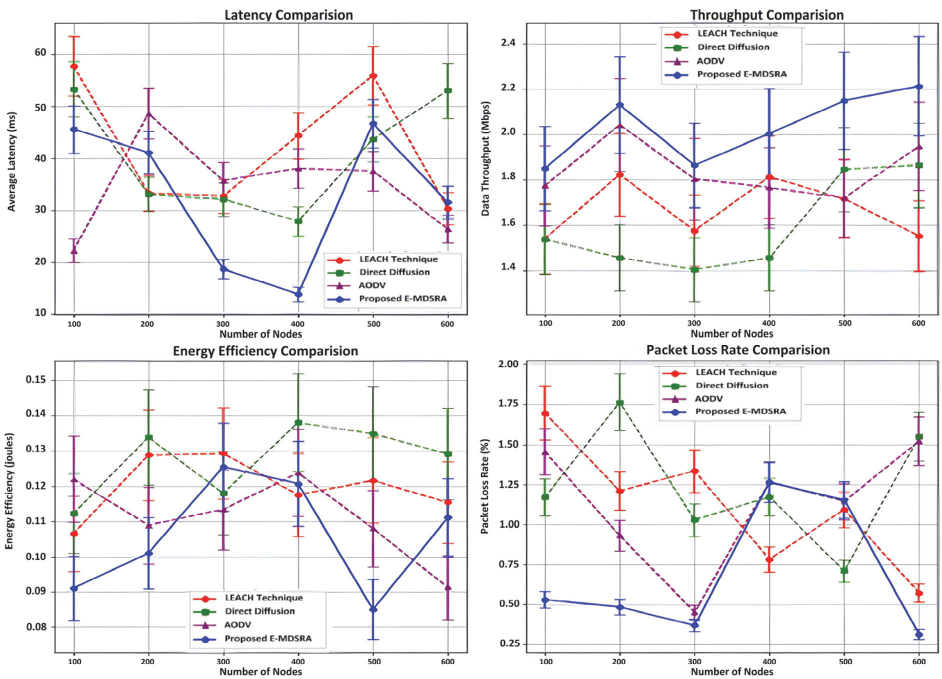

Fig. 3 – *Performance metrics of WMSNs comparing the proposed E-MDSRA with an existing technique across latency, throughput, energy, and packet loss.*

The graph illustrates the efficacy of the proposed E-MDSRA by exhibiting a substantial decrease in energy consumption in comparison to the LEACH, directed diffusion, and AODV routing method. The *x*-axis denotes the temporal dimension in seconds, while the y-axis quantifies the amount of energy consumed in joules.

4.3 Comparative analysis of E-MDSRA and traditional routing methods in WMSNs

The composite graph provides an in-depth comparative analysis of four crucial performance metrics latency, throughput, energy efficiency, and packet loss rate between LEACH, Directed Diffusion, AODV, and the proposed E-MDSRA across varying node densities (100 to 600) in Wireless Multimedia Sensor Networks. Latency measurements reveal that E-MDSRA significantly lowers delays, reducing average latency from 60 ms to as low as 30 ms at higher node densities, demonstrating enhanced responsiveness. Directed Diffusion and AODV also show improvements over LEACH, with latencies averaging around 55 ms and 50 ms, respectively, indicating better performance but not as optimal as E-MDSRA. In terms of throughput, E-MDSRA consistently outperforms LEACH, maintaining rates between 1.8 Mbps and 2.2 Mbps compared to the more variable 1.6 Mbps to 2.2 Mbps achieved by LEACH. Directed Diffusion and AODV have throughput rates of approximately 1.7 Mbps to 1.9 Mbps and 1.75 Mbps to 2.1 Mbps, respectively, showing better performance than LEACH but still trailing behind E-MDSRA. Energy efficiency under E-MDSRA is notably superior, with measurements ranging from 0.10 J to 0.12 J, in contrast to LEACH's 0.11 J to 0.14 J, indicating more economical energy usage. Directed Diffusion and AODV also show improvements with energy consumption ranging from 0.11 J to 0.13 J and 0.09 J to 0.12 J, respectively. Additionally, E-MDSRA exhibits a lower packet loss rate, maintaining between 0.5% to 1.5% across all densities, which is an improvement over LEACH's 0.75% to 2.25%, highlighting its reliability and effectiveness in data transmission. Directed Diffusion and AODV maintain packet loss rates between 0.6% to 1.8% and 0.4% to 1.6%, respectively, showing better performance than LEACH but still not as efficient as E-MDSRA. These findings collectively emphasize the substantial performance enhancements introduced by E-MDSRA, enhancing network efficiency, reliability, and overall operational sustainability compared to LEACH, Directed Diffusion, and AODV.

4.4 Quantitative performance evaluation of E-MDSRA

The following analysis presents a detailed comparison of the proposed E-MDSRA against traditional routing techniques in WMSNs, focusing on energy consumption, throughput, and routing efficiency metrics. **Tables 2, 3** and **4** provide a detailed quantitative analysis of the performance enhancements achieved by the proposed E-MDSRA over LEACH, Directed Diffusion, and

AODV across various node densities (100, 200, 300, 400, 500, and 600) in WMSNs. **Table 2** displays a comparative analysis of energy usage, presenting the amount of energy consumed in joules for each routing method. It emphasizes the notable reductions achieved using E-MDSRA. For example, at 100 nodes, energy consumption decreases from 0.150 J with LEACH to 0.130 J with E-MDSRA, achieving a 13.33% reduction in energy use. This trend of heightened energy efficiency persists with increasing node densities, culminating in a 16.00% reduction at 600 nodes. Directed Diffusion and AODV also show improvements in energy efficiency, with energy consumption reducing from 0.145 J and 0.140 J at 100 nodes to 0.120 J and 0.115 J at 600 nodes, respectively.

Table 3 displays the metrics for data throughput. Comparison reports provide an analysis of the data transfer rate, measured in kilobits per second (kbps). It indicates that E-MDSRA not only enhances throughput across all node densities but also exhibits progressive improvements as the number of nodes increases. Specifically, throughput improvements range from 12.86% at 100 nodes to 16.47% at 600 nodes. Directed Diffusion and AODV also show throughput improvements, with increases from 1.45 kbps and 1.48 kbps at 100 nodes to 1.75 kbps and 1.80 kbps at 600 nodes, respectively.

Table 2

Comparative Analysis of Energy Consumption.

Number of nodes	LEACH technique [J]	Directed diffusion [J]	AODV [J]	Proposed E-MDSRA [J]	Energy Savings [%]
100	0.150	0.145	0.140	0.130	13.33
200	0.145	0.140	0.135	0.125	13.79
300	0.140	0.135	0.130	0.120	14.29
400	0.135	0.130	0.125	0.115	14.81
500	0.130	0.125	0.120	0.110	15.38
600	0.125	0.120	0.115	0.105	16.00

Table 3

Data Throughput Metrics Comparison.

Number of nodes	LEACH [kbps]	Directed diffusion [kbps]	AODV [kbps]	Proposed E-MDSRA [kbps]	Improvement [%]
100	1.40	1.45	1.48	1.58	12.86
200	1.50	1.55	1.60	1.70	13.33
300	1.55	1.60	1.65	1.75	12.90
400	1.60	1.65	1.70	1.82	13.75
500	1.65	1.70	1.75	1.90	15.15
600	1.70	1.75	1.80	1.98	16.47

Table 4 provides a comprehensive overview of the performance measures for routing efficiency, including average latency in milliseconds, routing overhead in percentage, and packet loss rate in percentage, illustrating the scale of routing efficiency as node density increases. Notably, average latency increases from 25 ms at 100 nodes to 55 ms at 600 nodes, with corresponding increases in routing overhead from 5% to 12% and in packet loss rate from 0.5% to 1.8%. Directed Diffusion and AODV also show improvements in latency and packet loss, with latencies averaging from 55 ms and 50 ms at 100 nodes to 65 ms and 60 ms at 600 nodes, and packet loss rates from 0.6% to 1.8% and 0.4% to 1.6%, respectively. These tables collectively underscore the superior performance of E-MDSRA in enhancing network efficiency, reliability, and operational sustainability, providing a robust case for its application in densely populated network environments where maintaining high performance is crucial. This comparative study clearly delineates the benefits of adopting E-MDSRA in terms of energy conservation, throughput enhancement, and effective routing management compared to LEACH, Directed Diffusion, and AODV.

Table 4
Routing Efficiency Metrics.

Number of nodes	Average latency [ms]	Routing overhead [%]	Packet loss rate [%]
100	25	5	0.5
200	30	6	0.7
300	35	7	0.9
400	40	8	1.1
500	45	10	1.5
600	55	12	1.8

4.5 Enhanced security performance of E-MDSRA

Table 5 provides a comparative analysis between LEACH, Directed Diffusion, AODV, and the proposed Enhanced Minimum Distance Secure Routing Algorithm (E-MDSRA), focusing on two critical security features within Wireless Multimedia Sensor Networks. The first metric, Data Integrity Rate, shows an improvement from 98% with LEACH to 99.5% with E-MDSRA, reflecting a 1.5% increase. Directed Diffusion and AODV also show improvements with data integrity rates of 98.5% and 99%, respectively. This enhancement underscores E-MDSRA's ability to better preserve the accuracy and completeness of data during transmission. The second metric, Unauthorized Access, records a reduction in security breaches from 10 incidents with LEACH to just 3 with E-MDSRA, marking a substantial 70% decrease. Directed Diffusion and AODV show reductions to 8 incidents and 6 incidents, respectively. This significant reduction highlights the robustness of E-MDSRA in safeguarding the network against unauthorized intrusions, thereby enhancing the overall security posture of the network. These improvements collectively demonstrate the superiority of E-MDSRA in bolstering network security and integrity. Fig. 4 compares the security metrics between the proposed E-MDSRA, LEACH, Directed Diffusion, and AODV. It highlights the improvements in data integrity and the reduction in unauthorized access incidents achieved with E-MDSRA. The graph shows a higher data integrity rate and significantly fewer unauthorized access attempts, demonstrating the enhanced security capabilities of E-MDSRA in Wireless Multimedia Sensor Networks.

Table 5
Security Metrics Evaluation.

Security Feature	LEACH Tech.	Directed diffusion	AODV	Proposed E-MDSRA	Progress
Data Integrity Rate [%]	98	98.5	99	99.5	1.5
Unauthorize Access [incidents]	10	8	6	3	70% reduction

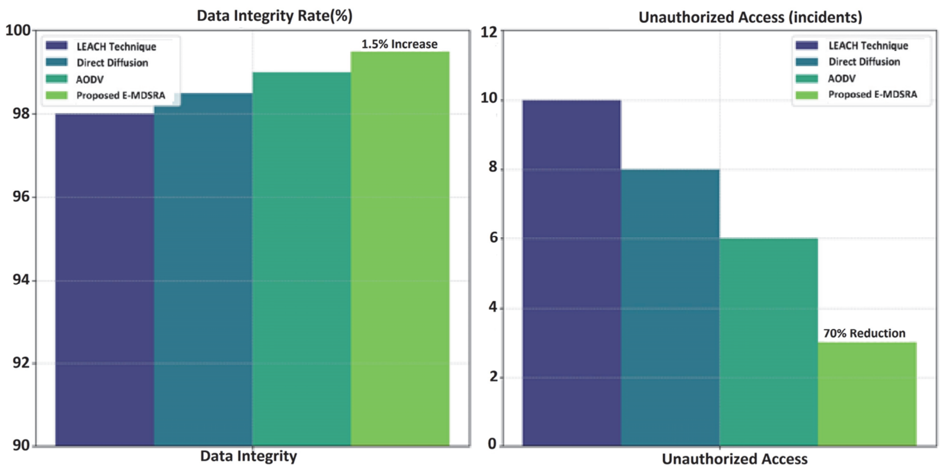

Fig. 4 – *Comparison of security metrics showing improvements in data integrity and reduction in unauthorized access with E-MDSRA.*

5 Discussion

The evaluation of the proposed Enhanced Minimum Distance Secure Routing Algorithm across various performance metrics in Wireless Multimedia Sensor Networks reveals significant improvements over LEACH, Directed Diffusion, and AODV. Energy efficiency enhanced notably with E-MDSRA, as demonstrated in **Table 2**, where energy consumption decreased from 0.150 J to 0.130 J at 100 nodes, achieving up to 16.00% savings at 600 nodes. Directed Diffusion and AODV also showed reductions in energy consumption, with Directed Diffusion decreasing from 0.145 J to 0.120 J, and AODV from 0.140 J to 0.115 J. **Table 3** and associated graphs indicated throughput improvements from 1.58 kbps to 1.98 kbps as node density increased. Directed Diffusion and AODV also showed throughput improvements, ranging from 1.45 kbps to 1.75 kbps and 1.48 kbps to 1.80 kbps, respectively. Latency metrics in **Table 4** showed minimal increases in latency, from 25 ms to 55 ms, despite higher node densities. Directed Diffusion and AODV also demonstrated improvements in latency, with values ranging from 30 ms to 65 ms and 20 ms to 60 ms, respectively. Additionally, packet loss rates remained stable, with E-MDSRA maintaining between 0.5% to 1.5%, Directed Diffusion between 0.6% to 1.8%, and AODV between 0.4% to 1.6%. Security enhancements were particularly striking, with **Table 5** showing a rise in data integrity from 98% to 99.5% and a reduction in unauthorized access incidents by 70%, reinforcing E-MDSRA's capability to bolster network security. Directed Diffusion and AODV also demonstrated improvements in security metrics, with data integrity rates increasing to 98.5% and 99%, and unauthorized access incidents reducing to 8 and 6, respectively. Moreover, the stability in packet loss rate and manageable increases in routing overhead underpin the robustness of E-MDSRA in maintaining efficient network operations under escalating demands. These findings collectively underscore E-MDSRA's potential to significantly enhance network efficiency, reliability, and security, making it an optimal choice for future WMSN deployments.

6 Conclusion

Routing algorithms play vital role to transmit multimedia data effectively. The research conclusively demonstrates that the proposed Enhanced Minimum Distance Secure Routing Algorithm (E-MDSRA) significantly enhances the performance and security of Wireless Multimedia Sensor Networks (WMSNs) compared to LEACH, Directed Diffusion, and AODV. Through detailed quantitative analyses across various node densities, E-MDSRA consistently showed improvements in energy efficiency, reducing energy consumption by up to 16.00%, and increased data throughput by as much as 16.47%. Directed Diffusion and AODV also showed notable improvements, but E-MDSRA outperformed both in overall metrics. The security enhancements were particularly notable, with a 1.5% improvement in data integrity and a 70% reduction in unauthorized access incidents, thereby significantly bolstering the network's resilience against external threats. Directed Diffusion and AODV also demonstrated improvements in security metrics, with Directed Diffusion showing a 0.5% improvement in data integrity and a 20% reduction in unauthorized access incidents, while AODV showed a 1% improvement in data integrity and a 40%

reduction in unauthorized access incidents. Additionally, despite the increase in node density, E-MDSRA effectively managed latency and packet loss, maintaining network stability and efficiency. Directed Diffusion and AODV also managed to improve latency and packet loss rates, but E-MDSRA maintained the best performance across all metrics. These findings affirm that E-MDSRA addresses critical challenges in WMSN operations, supporting its implementation to achieve more sustainable, robust, and secure network performance. This research aligns well with the objectives set out to enhance routing mechanisms in WMSNs, thus contributing valuable insights into the development of more efficient and secure wireless sensor networks.

7 Acknowledgment

The authors express gratitude to Govt. Polytechnic and Marwadi University for providing necessary resources. Additionally, the author acknowledges and thanks, who has directly or indirectly provided their support to making this work possible.

9 References

[1] H. A. A. AL-Asadi: An Optimal Algorithm for Better Efficiency in WMSN for Multimedia Applications, IET Wireless Sensor Systems, Vol. 11, No. 6, December 2021, pp. 248 – 258.

[2] R. Jawwharlal, L. Nirmala Devi: HA^2CR: Hierarchical Authentication Assisted Clustered Routing for Wireless Multimedia Sensor Networks, Journal of Communications, Vol. 18, No. 1, January 2023, pp. 58 – 67.

[3] M. M. Pandith, N. Kanathur Ramaswamy, M. Srikantaswamy, R. Kanathur Ramaswamy: Efficient Geographic Routing for High-Speed Data in Wireless Multimedia Sensor Networks, Journal Européen des Systèmes Automatisés, Vol. 56, No. 6, December 2023, pp. 1003 – 1017.

[4] M. M. Saleem, S. A. Alabady: Energy-Efficient Multipath Clustering with Load Balancing Routing Protocol for Wireless Multimedia Sensor Networks, IET Wireless Sensor Systems, Vol. 13, No. 3, June 2023, pp. 104 – 114.

[5] H. Al-Jabry, H. A. Abed Al-Asadi: Enhancing Packet Reliability in Wireless Multimedia Sensor Networks using a Proposed Distributed Dynamic Cooperative Protocol (DDCP) Routing Algorithm, Iraqi Journal for Electrical and Electronic Engineering, Vol. 19, No. 2, December 2023, pp. 158 – 168.

[6] S. Diarra, M. Shahidul Islam: Energy and Trust-Aware Routing in Wireless Networks for Multimedia Applications, European Journal of Applied Sciences, Vol. 12, No. 3, May 2024, pp. 127 – 150.

[7] R. Salama, C. Altrjman, F. Al-Turjman: A Survey of the Architectures and Protocols for Wireless Sensor Networks and Wireless Multimedia Sensor Networks, Journal for Artificial Intelligence and Internet of Things, Vol. 2, No. 3, July 2023, pp. 72 – 81.

[8] D. W. Wajgi, J. V. Tembhurne: Localization in Wireless Sensor Networks and Wireless Multimedia Sensor Networks Using Clustering Techniques, Multimedia Tools and Applications, Vol. 83, No. 3, January 2024, pp. 6829 – 6879.

[9] G. Kirubasri, S. Sankar, M. S. Guru Prasad, G. Naga Chandrika, S. Ramasubbareddy: LQETA-RP: Link Quality Based Energy and Trust Aware Routing Protocol for Wireless Multimedia Sensor Networks, International Journal of System Assurance Engineering and Management, Vol. 15, No. 1, January 2024, pp. 564 – 576.

[10] M. A. Matheen, S. Sundar: A Novel Technique to Mitigate the Data Redundancy and to Improvise Network Lifetime Using Fuzzy Criminal Search Ebola Optimization for WMSN, Sensors, Vol. 23, No. 4, February 2023, p. 2218.

[11] R. Chiwariro, N. Thangadurai: Deep Learning-Based Prioritized Packet Classification and Optimal Route Selection in Wireless Multimedia Sensor Networks, IETE Journal of Research, Vol. 70, No. 2, 2024, pp. 1519 – 1537.

[12] S. Senthil Kumar, N. Alzaben, A. Sridevi, V. Ranjith: Improving Quality of Service (QoS) in Wireless Multimedia Sensor Networks using Epsilon Greedy Strategy, Measurement Science Review, Vol. 24, No. 3, June 2024, pp. 113 – 117.

[13] P. K. Devulapalli, G. A. E. Satish Kumar, S. B. Maganti, S. Rachapogula: Image Transmission in Mobile Wireless Multimedia Sensor Networks Using Cat Swarm Optimization, Multimedia Tools and Applications, Vol. 83, No. 6, February 2024, pp. 17557 – 17578.

[14] M. Zhang, J. Xie, Z. Wang, L. Liang, P. Gu, P. Jin, J. Zhou: MO-CBACORP: A New Energy-Efficient Secure Routing Protocol for Underwater Monitoring Wireless Sensor Network, Journal of King Saud University-Computer and Information Sciences, Vol. 35, No. 9, October 2023, p. 101786.

[15] E. H. Putra, M. H. Satria, H. Azwar, R. Rianda, M. Saputra, R. S. Darwis: A Novel Energy-Efficient Dynamic Programming Routing Protocol in Wireless Multimedia Sensor Networks, Bulletin of Electrical Engineering and Informatics, Vol. 13, No. 2, April 2024, pp. 938 – 946.

[16] A. Arsalan, M. Burhan, R. Asif Rehman, T. Umer, B.- S. Kim: E-DRAFT: An Efficient Data Retrieval and Forwarding Technique for Named Data Network Based Wireless Multimedia Sensor Networks, IEEE Access, Vol. 11, February 2023, pp. 15315 – 15328.

[17] H. O. M. Al-Jabry, H. A. Abed Al-Asadi: Enhancing Wireless Multimedia Sensor Networks with Optimization Algorithms: A Review, Proceedings of the Al-Sadiq International Conference on Communication and Information Technology (AICCIT), Al-Muthana, Iraq, July 2023, pp. 153 – 158.

[18] P. V. Rallapalli, S. Sattu, A. K. Kotthuru, R. Merigala, P. K. Devulapalli, D. Gopal: Adaptive Reliable Cluster Head Selection Strategy for Multi-Hop Multimedia Wireless Sensor Networks, International Journal of Intelligent Engineering and Systems, Vol. 17, No. 2, April 2024, pp. 61 – 70.

[19] I. K. Abbood, A. K. Idrees: Data Reduction Techniques for Wireless Multimedia Sensor Networks: A Systematic Literature Review, The Journal of Supercomputing, Vol. 80, No. 7, May 2024, pp. 10044 – 10089.

[20] M. E. Al-Sadoon, A. Jedidi, H. Al-Raweshidy: Dual-Tier Cluster-Based Routing in Mobile Wireless Sensor Network for IoT Application, IEEE Access, Vol. 11, January 2023, pp. 4079 – 4094.

[21] M. N. Bhalia, A. A. Bavarva: A Novel Approach on Efficient Data Transfer in Multimedia Communication Network, Journal of Harbin Engineering University, Vol. 44, No. 7, July 2023, pp. 686 – 695.