JOURNAL OF BASIC SCIENCE AND ENGINEERING

Enhancing Security in Mobile Wireless Sensor Networks:Advanced Encryption, Dynamic Key Management, and Intrusion Detection Systems

[1]Amit Mohan Totade, [2] B.G Nagaraja, [3] Rajesh Maharudra Patil

[1]Research scholar of the Visvesvaraya Technological University (VTU), Belagavi, Karnataka
[2]Associate Professor, Vidyavardhaka College of Engineering, Mysuru, Karnataka
[3] Professor, department of Electrical Engineering, Visvesvaraya Technological University, Regional Center, Belagavi, Karnataka

DOI: https://doie.org/10.0913/Jbse.2024767378

Received: May 2024 **Revised:** July 2024 **Accepted:** September 2024

ABSTRACT

Security in Mobile Wireless Sensor Networks (MWSNs) is crucial due to the sensitive nature of data transmission and the resource constraints of sensor nodes. This paper presents a comprehensive approach to enhancing security in MWSNs by integrating advanced encryption algorithms, dynamic key management protocols, and intrusion detection systems (IDS). The proposed enhancements aim to mitigate vulnerabilities and improve the overall robustness of MWSNs while maintaining operational efficiency. Experimental results demonstrate the effectiveness of these security mechanisms in terms of computational overhead, communication latency, and energy consumption, ensuring that the enhanced security measures do not significantly degrade network performance.

Keywords: Mobile Wireless Sensor Networks, Security, Encryption, Dynamic Key Management, Intrusion Detection Systems.

1. INTRODUCTION

In the context of Mobile Wireless Sensor Networks (MWSNs), security remains a paramount concern due to the sensitive nature of the data transmitted and the resource constraints of the sensor nodes. The dynamic topology and the wireless communication medium make MWSNs particularly vulnerable to various security threats, such as eavesdropping, data tampering, and denial-of-service attacks.

Previous research has laid the groundwork by discussing the fundamental aspects of key management schemes within MWSNs, highlighting their critical role in ensuring secure communication. Building on this foundation, this paper focuses on the second research objective: enhancing the security mechanisms integrated into the key management scheme. The aim is to propose, implement, and evaluate novel security enhancements that address existing vulnerabilities in MWSNs. These enhancements are designed to bolster the overall security posture of the network while maintaining or improving its performance. Key areas of focus include the integration of advanced encryption algorithms, the implementation of dynamic key management protocols, and the deployment of intrusion detection systems.

The motivation behind this research stems from the critical need to protect sensitive information in MWSNs, which are used in applications where data integrity and confidentiality are crucial. Existing security mechanisms often fall short due to the resource constraints and dynamic nature of MWSNs. By developing and implementing enhanced security measures, this research aims to provide a more robust solution thatcan be practically deployed in real-world MWSN applications.

The aim of this research is to propose, implement, and evaluate novel security enhancements that address the existing vulnerabilities in MWSNs. The specificobjectives are:

- To integrate advanced encryption algorithms that are suitable for resource- constrained sensor nodes.
- To implement dynamic key management protocols that periodically update keysto enhance security.
- To deploy intrusion detection systems (IDS) that monitor network traffic forsuspicious activity and provide alerts for potential security breaches.

The remainder of this paper is structured as follows: Section 2 reviews the related workon key management and security in MWSNs. Section 3 presents the proposed security enhancements, detailing the integration of advanced encryption algorithms, dynamic key management, and intrusion detection systems. Section 4 discusses the experimental setup and performance evaluation. Section 5 presents the results and discussion, and Section 6 concludes the paper with insights on future work.

2. RELATED WORK

This section reviews existing literature on key management schemes and security mechanisms in Mobile Wireless Sensor Networks (MWSNs). Key management is crucial for ensuring secure communication in MWSNs, and various schemes have been proposed to address different aspects of security. Traditional methods such as static key management schemes have limitations in terms of scalability and security due to their fixed nature. More recent approaches have introduced dynamic key management protocols and lightweight encryption algorithms to enhance security and efficiency. Additionally, IDS have been developed to monitor network traffic and detect potential threats. However, these existing methods often face challenges related to resource constraints, computational overhead, and adaptability to dynamic network topologies.

Recent studies have focused on dynamic key management protocols to address the limitations of static key schemes. For instance, [1] proposed a dynamic key managementscheme that leverages blockchain technology to ensure secure and efficient key distribution in MWSNs. The proposed scheme demonstrated improved security and reduced computational overhead compared to traditional methods. The integration of lightweight encryption algorithms has been a significant focus in recent research. The work in [2] introduced a lightweight encryption algorithm tailored for resource- constrained sensor nodes in MWSNs. Their approach showed a balance between security and energy consumption, making it suitable for practical deployment in MWSNs.

The use of IDS in MWSNs has been extensively explored to enhance network security. In a recent study, [3] developed an anomaly-based IDS using machine learning techniques to detect malicious activities in MWSNs. Their system achieved high detection accuracyand low false-positive rates, demonstrating the effectiveness of IDS in securing MWSNs. Advances in quantum key distribution (QKD) have also been explored for securing MWSNs. Study in [4] investigated the feasibility of integrating QKD with traditional key management schemes in MWSNs. Their findings indicated that QKD could provide a higher level of security, albeit with increased complexity and resource requirements.

Secure routing protocols have been proposed to mitigate routing-based attacks in MWSNs. The work in [5] presented a secure routing protocol that combines cryptographic techniques with trust-based mechanisms to ensure secure data transmission. Their protocol showed resilience against various attacks, including Sybil and wormhole attacks. These literature outcomes highlight the ongoing efforts and advancements inenhancing the security of MWSNs through dynamic key management, lightweight encryption, IDS, QKD, and secure routing protocols. Despite these advancements, challenges remain in achieving optimal security without compromising the performance and efficiency of MWSNs. The proposed security enhancements in this paper aim to address these challenges by integrating advanced encryption algorithms, dynamic key management, and intrusion detection systems, thereby providing a comprehensive solution for securing MWSNs.

3. PROPOSED ALGORITHM

3.1 Enhanced Encryption Algorithms

Encryption is a cornerstone of security in MWSNs. The proposed enhancement involves integrating advanced encryption algorithms, specifically focusing on lightweight cryptographic techniques that are suitable for resource-constrained sensor nodes [6]. The choice of encryption algorithms is crucial. We propose using the Advanced Encryption Standard (AES) with a 128-bit key due to its balance of security and efficiency. Additionally, elliptic curve cryptography (ECC) is considered for its strong security per bitof key length [7].

AES is a symmetric encryption algorithm that operates on fixed block sizes of 128 bits. It uses a series of transformations, including substitution, permutation, and mixing, which are applied repeatedly in several rounds [8]. The number of rounds depends on the key size. ECC is based on the algebraic structure of elliptic curves over finite fields. It provides the same level of security as traditional public-key algorithms (like RSA) but with much shorter key lengths [9]. An elliptic curve is defined by the equation:

$$y^2 = x^3 + ax + b$$

where a and b are constants that satisfy $4a^3 + 27b^2 \neq 0$.

Static key management schemes are vulnerable to various attacks due to the extended lifetime of keys. To mitigate these vulnerabilities, we propose a dynamic key managementscheme where keys are updated periodically and on-demand [10]. Keys are updated using a combination of time-based and event-based triggers. A pseudo-random function(PRF) is used to generate new keys from a master key:

$$K_{i+1} = P(K_i, T_i)$$

where K_i is the current key, T_i is the current timestamp or event identifier, and PRF is thepseudo-random function.

3.2 Intrusion Detection Systems

To further secure MWSNs, an IDS is integrated into the network. This IDS monitors network traffic for suspicious activity and provides alerts for potential security breaches. The IDS uses anomaly detection techniques to identify deviations from normal behavior [11]. The detection process can be mathematically represented as:

$$f(x) = \begin{cases} 1; & |x - \mu| > \theta \\ 0; & otherwise \end{cases}$$

where x is the observed data point, μ is the mean of the normal data distribution, and θ is a predefined threshold.

The impact of the proposed security enhancements on MWSNs is evaluated based on several metrics, including encryption overhead, key update frequency, and IDS detection rates. The aim is to ensure that the enhanced security mechanisms do not significantly degrade the network's operational efficiency while providing robust protection againstvarious threats [12].

4. EXPERIMENTAL SETUP

A simulated MWSN is configured to evaluate the proposed security key enhancement schemes under various network conditions. The network includes different node densities (low, medium, high) and mobility patterns to thoroughly assess the performance and scalability of the proposed solutions [13].

Table 1: Example configuration.

Low Density	Medium Density	High Density
Number of nodes: 50	Number of nodes: 100	Number of nodes: 200
Area: 1000m x 1000m	Area: 1000m x 1000m	Area: 1000m x 1000m
Node distribution: Sparse	Node distribution: Moderate	Node distribution: Dense

In this example, we configure a high-density network with 200 nodes distributed over an area of 1000 m × 1000 m. Each node moves according to the Random Waypoint Mobility model, with a speed ranging from 0.5 m/s to 2 m/s. The nodes pause for a random duration between movements, simulating real-world scenarios where sensor nodes might remain stationary for a period before moving to a new location. Simulation Parameters

- Simulation Area: 1000m x 1000m
- Number of Nodes: 200
- Mobility Model: Random Waypoint
- Node Speed: 0.5 m/s to 2 m/s
- Pause Time: 0 to 20 seconds
- Transmission Range: 100m
- Simulation Time: 1000 seconds

5. RESULTS AND DISCUSSIONS

The computational overhead is measured by the time taken for key management operations. Results are presented in Table 2.

Table 2: Performance Metrics for Different Node Densities in MWSNs

Node Density	Encryption Time (ms)	Decryption Time (ms)	Key Management Time (ms)
Low	15	12	10
Medium	22	18	15
High	30	25	20

The communication latency, including protocol overhead, is shown in Table 3.

Table 3: Latency and Overhead for Different Node Densities in MWSNs

Node Density	Latency (ms)	Overhead (ms)

Low	15	12
Medium	22	18
High	30	25

The energy consumption for different node densities is analyzed to ensure the proposed enhancements do not significantly increase the energy burden on sensor nodes. Results are presented in Table 4.

Table 4: Energy Consumption for Different Node Densities in MWSNs

Node Density	Energy Consumption (J)
Low	0.5
Medium	0.8
High	1.2

The results indicate that while the proposed security enhancements introduce some computational overhead and communication latency, these increases are within acceptable limits given the significant improvements in network security. The energy consumption analysis confirms that the enhancements are feasible for resource- constrained sensor nodes [14-15].

6. CONCLUSIONS AND FUTURE WORK

This paper presents a comprehensive approach to enhancing the security of Mobile Wireless Sensor Networks through the integration of advanced encryption algorithms, dynamic key management protocols, and intrusion detection systems. The proposed enhancements address existing vulnerabilities and improve the overall robustness of MWSNs while maintaining operational efficiency. Future work will focus on further optimizing the security mechanisms to reduce overhead and exploring additional security measures to counter emerging threats in MWSNs.

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