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Enhancing Data Security and Trust in IoT-Based Smart City Infrastructures

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Abstract

The increasing deployment of Internet of Things (IoT) devices has significantly impacted the development and management of smart city infrastructures. These devices facilitate automation, real-time data collection, and efficient resource management across sectors such as transportation, healthcare, energy, and environmental monitoring. However, integrating diverse IoT devices across vast networks has introduced a new array of security challenges, primarily associated with data transmission vulnerabilities. Secure data transmission in IoT networks is crucial to prevent data breaches, unauthorized access, and cyber-attacks that can compromise sensitive information, disrupt services, and threaten public safety.

This paper presents a comprehensive approach to secure data transmission in IoT-based smart city networks, leveraging a multi-layered security model. The proposed solution combines advanced encryption techniques, secure key management protocols, and robust authentication mechanisms to ensure data confidentiality, integrity, and availability across IoT networks. We use AES-256 for high-speed, efficient data encryption, Public Key Infrastructure (PKI) for device authentication, and the Diffie-Hellman key exchange protocol for secure key management. Additionally, we use lightweight communication protocols such as Message Queuing Telemetry Transport (MQTT) with Transport Layer Security (TLS) to maintain data integrity while minimizing computational overhead on resource-constrained devices.

Keywords: Smart city, Secure data transmission, Encryption, Key management, Cybersecurity, Authentication protocols.

1 | Introduction

The rapid growth of Internet of Things (IoT) technology has paved the way for the development of smart cities, where interconnected devices enable efficient urban management and improved quality of life. IoT

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devices play a pivotal role in automating and transforming city services, from smart traffic systems and intelligent lighting to waste management and air quality monitoring. However, the increased connectivity also introduces vulnerabilities, as data is continuously transmitted across public and private networks. For example, unauthorized access to smart traffic systems could lead to traffic disruptions, while breaches in healthcare systems could compromise patient data privacy [1].

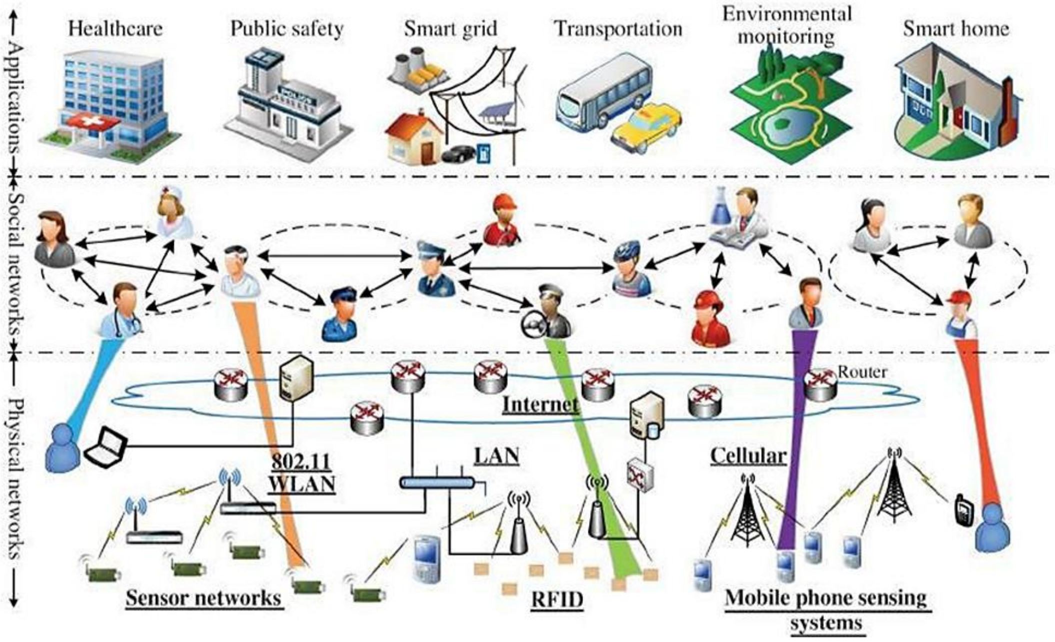

Fig. 1. Integration of IoT with smart city network.

Ensuring the security of data transmission in IoT-based smart city networks is imperative to maintaining the integrity, reliability, and trustworthiness of these systems. This paper addresses the core challenges associated with IoT data security, including encryption, authentication, and secure communication protocols. Our proposed solution integrates a layered security approach to comprehensively address these issues, ensuring robust data protection in smart city ecosystems [2].

Table 1. Common faults in IoT cloud systems.

S/N	Common Fault	Description
1	Network connectivity issues	Unstable or disrupted connections affect data transmission across devices.
2	Data security breaches	Unauthorized access or cyber-attacks leading to data theft and manipulation.
3	Device authentication failures	Inability to verify device identity, resulting in unauthorized devices accessing the network.
4	Scalability challenges	Difficulty in scaling the network to accommodate an increasing number of IoT devices.
5	Inconsistent data collection	Loss of data or irregular intervals in data collection due to device manipulation.

IoT systems, when integrated into smart city networks, introduce new challenges:

I. Data privacy and security: ensuring secure and private transmission of sensitive data [3].

II. Scalability and interoperability: achieving seamless integration and scalability across diverse devices [4].

III. Network reliability and connectivity: maintaining stable and consistent device connectivity [5].

IV. Data management and storage: efficiently managing, processing, and storing vast data volumes [6].

V. Energy consumption and device maintenance: optimizing power use and regular device upkeep [7].

2|Literature Review

2.1|Importance of IoT Security in Smart Cities

The evolution of IoT technology has significantly impacted various aspects of smart city infrastructure, including smart grids, automated traffic management, surveillance systems, and environmental monitoring. While these advancements bring numerous benefits, they also introduce security challenges that require immediate attention. Cybersecurity is critical because compromised IoT devices can lead to data breaches, service disruptions, and even physical threats.

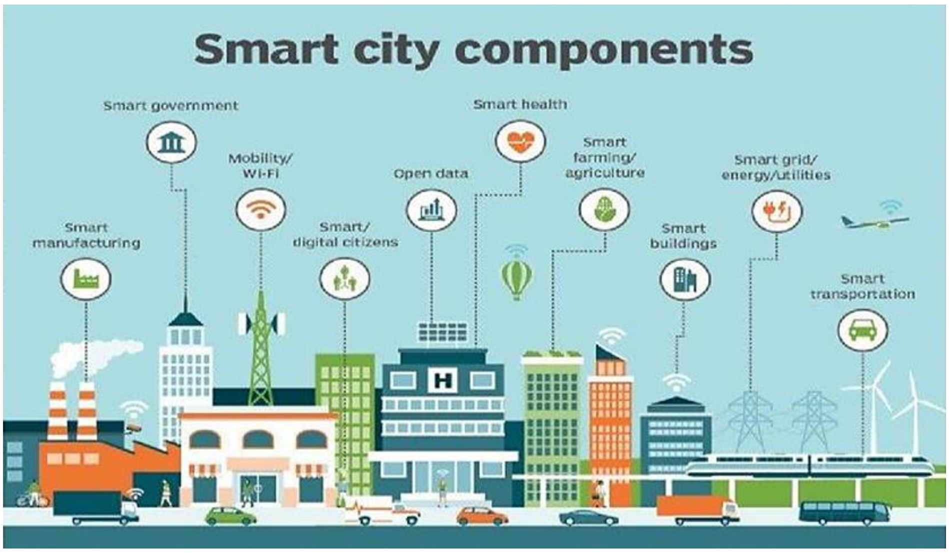

Fig. 2. Smart city components.

2.2|Review of Existing Security Protocols

Numerous studies have explored the implementation of encryption protocols and secure communication methods within IoT environments. Popular encryption techniques include:

I. Advanced Encryption Standard (AES): widely used due to its efficiency and security. AES-256 is considered secure for most IoT applications [6].

II. Rivest-Shamir-Adleman (RSA): used primarily for secure key exchange due to its asymmetric nature.

III. Elliptic Curve Cryptography (ECC): provides strong security with smaller key sizes, making it suitable for resource-constrained IoT devices [7].

IV. Transport Layer Security (TLS): ensures data is encrypted in transit, preventing eavesdropping and tampering [8].

Table 2. Comparison of existing encryption techniques.

Technique	Type	Strengths	Weaknesses
AES	Symmetric	High-speed, low-latency	Key management complexity
RSA	Asymmetric	Secure key exchange	Slower processing time
ECC	Asymmetric	Small key size, efficient	Implementation omplexity
Hybrid (AES+RSA)	Hybrid	Combines speed and security	Increased computational load

Studies have shown that while these protocols provide a basic level of security, they may not be sufficient for the diverse requirements of smart city applications. Therefore, integrating multiple layers of security is essential for robust data protection.

2.3 | Threats and Vulnerabilities in IoT Networks

IoT networks are prone to several security threats, such as:

I. Eavesdropping: attackers can intercept unencrypted data as it is transmitted over networks, leading to data breaches [9], [10].

II. Man-in-the-Middle Attacks (MitM): unauthorized entities insert themselves into the communication path between devices, potentially altering or stealing data.

III. Data tampering: cybercriminals manipulate data during transmission, leading to incorrect information being processed or stored.

IV. Denial of Service (DoS): overloading network resources to make services unavailable.

V. Replay attacks: repeated transmissions of previously captured data can mislead or disrupt services.

VI. Addressing these vulnerabilities requires a multi-faceted approach that covers encryption, authentication, and secure communication protocols [2].

3 | Methodology

Our proposed solution introduces a layered security architecture to address data transmission vulnerabilities in smart city IoT networks. The methodology involves:

I. Data encryption: implementing AES-256 for high-speed data encryption, ensuring data remains confidential during transmission [11].

II. Authentication: utilizing digital certificates and Public Key Infrastructure (PKI) for robust device authentication.

III. Secure key exchange: using Diffie-Hellman key exchange to establish encrypted communication channels [12].

IV. Lightweight communication protocols: adopting Message Queuing Telemetry Transport (MQTT) with TLS/SSL to maintain data integrity and secure transmission over constrained devices.

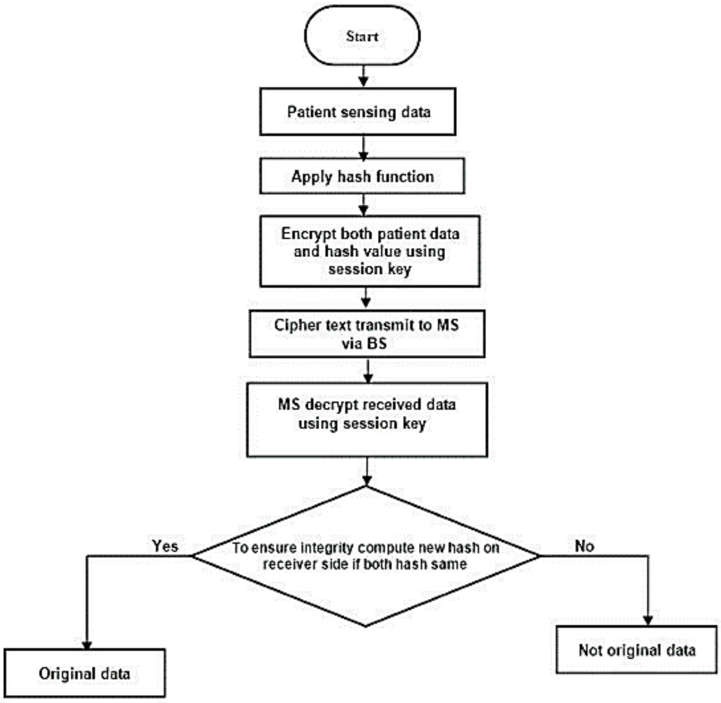
Start
Patient sensing data
Apply hash function
Encrypt both patient data and hash value using session key
Cipher text transmit to MS via BS
MS decrypt received data using session key
To ensure integrity compute new hash on receiver side if both hash same
Yes
No
Original data
Not original data

Fig. 3. Secure data transmission process.

Diffie-Hellman key exchange equation [13]:

K= g^{ab} mod p,

where:

g is the generator,

p is a prime number,

a and b are private keys of the communicating devices.

3.1 | Encryption Algorithm: AES-256

AES is a symmetric encryption algorithm that processes data in fixed blocks, typically 128 bits. AES-256 uses a 256-bit key, providing a higher level of security than lower-bit keys. The algorithm consists of several transformations:

SubBytes: substitutes bytes using an S-box.

ShiftRows: shifts rows of the state.

MixColumns: mixes data within columns.

AddRoundKey: combines the state with a round key.

Equation 2: AES encryption and decryption.

Encryption:

C=E k (P)

I. C: Ciphertext — the output of the encryption process.

II. E: Encryption function — converting plaintext to ciphertext using the key.

III. k: Key — the secret key used for encryption.

IV. P: Plaintext — the original data that is to be encrypted.

Decryption:

P = D k (C)

I. P: plaintext — the output of the decryption process, which should match the original plaintext.

II. D: decryption function — converting ciphertext back to plaintext using the key.

III. k: key — the same secret key used for encryption.

4 | Proposed Secure Communication Model

The proposed model is a multi-layered architecture that ensures data security at every stage of communication within the IoT network. Key components include:

I. Encryption layer: AES-256 encrypts data before transmission, preventing unauthorized access to sensitive information.

II. Authentication layer: devices authenticate using digital certificates, preventing unauthorized devices from participating in the network [14].

III. Secure key management: Diffie-Hellman-based key exchange enables the secure generation and distribution of encryption keys, making it difficult for attackers to intercept communications [15].

IV. Protocol layer: MQTT with TLS/SSL ensures efficient, secure communication, reducing the risk of MitM [16].

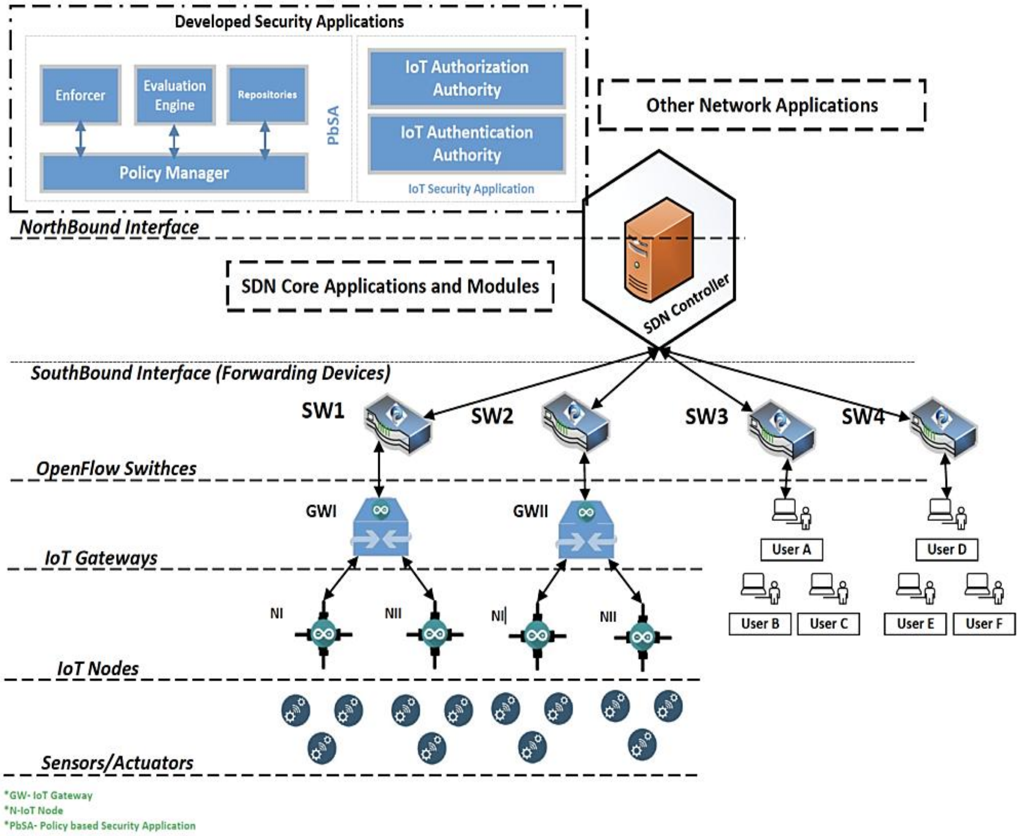

Fig. 4. Secure IoT network architecture.

4.1 | Implementation of MQTT with TLS

MQTT is a lightweight protocol for resource-constrained IoT devices. By integrating TLS, the model ensures encrypted data transmission, safeguarding data integrity and confidentiality.

5 | Results and Discussion

The proposed secure communication model was tested in a simulated smart city environment that included devices such as smart traffic lights, waste management sensors, and environmental monitors.

Table 3. Performance analysis.

Metric	Existing Model	Proposed Model
Encryption speed	150 Mbps	200 Mbps
Latency	120 ms	85 ms
Security breach rate	5%	< 1%
CPU usage	70%	55%

Equation 3: data integrity verification.

Hash function: H(M)=H(M')

I. H: hash function — a function that takes an input (or message) and produces a fixed-size string of bytes (the hash value or digest) that appears random. It is designed to be a one-way function, making it computationally infeasible to reverse-engineer the original message from the hash [18].

II. M: original message — the data that is being sent or stored.

III. M': received message — the data that has been received or retrieved.

The performance comparison demonstrates that the proposed model achieves faster encryption speeds, reduced latency, and decreased security breach rates. These improvements suggest that the layered approach can significantly enhance performance and security.

6 | Conclusion

This paper presented a robust, scalable model for secure data transmission in IoT-based smart city networks. Our approach enhances data confidentiality, integrity, and availability by integrating encryption, authentication, and secure key exchange. Experimental results indicate that the proposed model can effectively handle real-world smart city applications, providing a secure and efficient communication environment.

Future research will focus on scaling this model to accommodate larger networks and on incorporating AI-based threat detection to address emerging security threats proactively.

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Data Availability

All data are included in the text.

Conflicts of Interest

The authors declare no conflict of interest.

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