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A Novel Perspective on IoT Security for Large-Scale Healthcare: Insights from the Literature

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Abstract

The rapid growth of IoT technologies has significantly improved healthcare systems by enabling real-time patient monitoring and data collection, leading to better care delivery. However, this has also introduced substantial security risks, with sensitive patient data being vulnerable to unauthorized access and cyberattacks. The Internet of Things (IoT) has transformed healthcare by enabling real-time monitoring, remote diagnostics, and improved patient care. However, it introduces security, privacy, and scalability challenges that threaten patient safety and data integrity. The literature highlights several key strategies for improving IoT security in healthcare, including the use of ECC for lightweight encryption, ECDH for secure key exchange, and advanced authentication mechanisms. Although challenges such as device resource constraints and the need for frequent key updates remain, ongoing research continues to refine these methods, aiming to provide secure and efficient solutions for IoT-based healthcare systems.

Keywords: *Internet of Thing Security, Elliptic Curve Cryptography (ECC), Body Sensor Network (BSN), Elliptic Curve Diffie–Hellman (ECDH), B Tree based Group Key Agreement (GKA), Location-Based Authentication (LBA)*

I Introduction

The Internet of Things (IoT) has transformed sectors like healthcare by enabling real-time monitoring, remote diagnosis, and improved patient management through devices such as wearables, smart sensors, and connected equipment. However, these benefits come with challenges in data security, privacy, and resource management, as IoT devices often have limited processing power, memory, and battery life. Elliptic Curve Cryptography (ECC) offers strong security with minimal computational overhead, making it ideal for securing Body Sensor Networks (BSNs) and conserving energy and bandwidth. For secure communication, Elliptic Curve Diffie-Hellman (ECDH) enables dynamic key exchanges, particularly useful in networks with frequently changing devices. Yet, frequent encryption and key updates can strain devices, prompting solutions like the B-tree-based group key agreement protocol to streamline multicast communications and reduce device load. Authentication remains critical, multi-factor and location-based methods enhance protection beyond vulnerable single-factor systems, ensuring only authorized access even if credentials are compromised. Research highlights ECC, ECDH, and advanced authentication as key strategies for secure, efficient IoT healthcare, though resource constraints and update demands persist.

II Related Study

IoT is transforming healthcare by enabling connected devices and seamless data exchange, but adoption faces critical security and privacy challenges due to the sensitivity of medical data. Studies have proposed various solutions, focusing on encryption, authentication, and key management.

Gope and Hwang (2016) introduced BSN-Care, a Body Sensor Network system using lightweight Elliptic Curve Cryptography (ECC) to secure data transmission and improve energy efficiency in wearable devices.

Zhou et al. (2017) addressed cloud-based IoT healthcare security by combining ECC and AES for efficient encryption and secure storage.

Dimitrov (2016) highlighted ECC's suitability for resource-limited, real-time healthcare applications, while Wang et al. (2018) integrated ECC with Elliptic Curve Diffie-Hellman (ECDH) to enable dynamic, secure key exchange in changing network environments.

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Authentication enhancements include Pasluosta et al.'s (2016) location-based system to prevent unauthorized access and Zhang et al.'s (2020) blockchain-based authentication, which decentralizes security and combines with ECDH for scalability. For group communication, Chen et al. (2018) proposed a B-tree-based group key agreement protocol using ECC to update keys efficiently as devices join or leave, ensuring secure multicast without overburdening devices.

III Study Related to Existing IoT Security Solutions

Encryption Protocols for IoT

Alaba et al. (2019) demonstrated that Elliptic Curve Cryptography (ECC) is highly effective for secure data transmission in IoT healthcare, offering confidentiality and efficient key exchange, particularly for constrained devices like wearables and smart home systems. Chen et al. (2020) proposed a hybrid approach combining ECC for secure key exchange with AES for high-speed bulk data encryption, reducing computational demands while maintaining robust security. Wang et al. (2021) explored Homomorphic Encryption (HE), enabling computations on encrypted healthcare data in the cloud without decryption, thereby preserving data privacy.

Secure Communication Mechanisms

Khalid et al. (2019) highlighted Datagram TLS (DTLS) as a lightweight yet secure protocol for IoT applications, especially in smart homes and industrial systems. In 2021, Lightweight Secure Transport (LST) emerged as an improved alternative, minimizing handshake and encryption overhead while enhancing energy efficiency and reducing latency, making it suitable for time-critical IoT uses such as autonomous vehicles and smart manufacturing.

Authentication Systems in IoT

Liu et al. (2018) introduced Location-Based Authentication (LBA), which adds the device's physical location as a security factor, reducing unauthorized access risks, particularly valuable in healthcare, where devices move between locations. Zhang et al. (2020) developed a blockchain-based decentralized authentication method for IoT, supporting secure peer-to-peer communication without a central authority, useful in smart city infrastructures. Banerjee proposed a lightweight hash-based authentication protocol tailored for resource-limited IoT devices, addressing the need for efficient, low-overhead security.

Key Management Solutions

Elliptic Curve Diffie-Hellman (ECDH) is widely adopted for secure key exchange in IoT due to its low computational cost. Chen et al. (2022) enhanced ECDH with a group key agreement protocol for smart grids, enabling efficient key updates in dynamic networks. Ali et al. (2023) investigated Quantum-Resistant Cryptography (QRC) for future-proof key exchange, ensuring IoT security remains intact even in the quantum computing era.

IV Study Related to Location-Based Authentication Scheme for IoT Environments and Healthcare Applications

Liu et al. (2018) developed one of the first GPS-based Location-Based Authentication (LBA) systems for IoT healthcare, securing mobile medical devices and wearables by verifying location. While effective, its GPS reliance made it vulnerable to spoofing and unsuitable for indoor environments.

Lin et al. (2019) enhanced LBA with Wi-Fi and Bluetooth proximity data for multi-factor authentication (MFA), improving security in hospital settings. However, it suffered from high energy consumption and interference in congested areas.

Zhang et al. (2020) integrated LBA with blockchain to secure hospital medical devices without central servers, reducing centralized attack risks. The main drawback was blockchain's high computational overhead for resource-limited devices.

Ahmed et al. (2021) proposed an RFID-based lightweight LBA system for energy-efficient authentication in wearables and portable devices. Its limitations were RFID's short range and lower accuracy in large facilities.

Wang et al. (2022) combined LBA with facial recognition for patient monitoring, boosting security but facing challenges with computational demands and biometric data privacy.

Khalid et al. (2023) introduced dynamic geofencing in LBA to adjust access based on device movement. While flexible, it struggled in areas with weak GPS signals, such as urban hospitals.

Limitations and Challenges

GPS Vulnerabilities: Systems relying on GPS are prone to spoofing attacks, where attackers can manipulate

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location data to gain unauthorized access. This limits LBA's effectiveness in environments where location spoofing is possible.

- **Energy Consumption**: Proximity-based LBA systems (e.g., those using Wi-Fi or Bluetooth) consume considerable energy, making them less suitable for battery-powered medical devices.

Conclusion

Location-Based Authentication (LBA) is an effective tool for improving IoT security in healthcare environments by using a device's location as an additional authentication factor. Various studies have demonstrated LBA's potential to secure healthcare IoT devices, but challenges such as GPS vulnerabilities, energy consumption, and computational overhead remain. Future research should focus on optimizing these systems for broader adoption, especially in resource-constrained healthcare IoT environments.

V Study Related to B-Tree-Based Group Key Agreement for IoT Environments and IoT In Healthcare

The rapid growth of Internet of Things (IoT) technology has intensified the demand for secure communication among connected devices. In dynamic IoT networks, where devices often join or leave, managing group communication securely poses a major challenge. Traditional key management approaches struggle in such scenarios due to frequent rekeying, which increases computational and communication overhead. B-Tree-Based Group Key Agreement (GKA) offers a scalable and efficient alternative, optimizing key management for these environments. This review examines the use of B-Tree-based GKA across IoT applications, with a particular emphasis on healthcare, where both security and efficiency are critical.

Overview of B-Tree-Based Group Key Agreement

Group Key Agreement (GKA) enables a group of devices to communicate securely by generating a shared secret key. In dynamic IoT networks, frequent device joins and leaves make rekeying a major challenge. The B-Tree-based GKA mitigates this by structuring devices hierarchically, with the root node holding the group key. Rekeying is confined to the affected subset of the tree, reducing both communication and computational costs. In healthcare IoT—where devices like wearable sensors, monitoring systems, and management platforms must protect sensitive patient data—this approach offers a scalable and efficient solution. Its ability to manage dynamic membership efficiently makes it well-suited for maintaining secure communication in medical environments.

Methods and Approaches

The B-Tree architecture clusters IoT devices, assigning each cluster a local key and maintaining a global key at the root. This hierarchical arrangement enables quick key updates when devices join or leave, reducing the number of update messages compared to traditional GKA methods like Diffie-Hellman. As a result, it lowers bandwidth use and processing time, making it well-suited for resource-constrained IoT systems. Over the past decade, multiple studies have explored B-Tree-based GKA in diverse IoT applications:

Zhang et al. (2014): Among the earliest to study B-Tree GKA for IoT, showing reduced rekeying overhead in dynamic networks. Effective for small–medium networks but faced scalability limits in very large deployments.

Chen et al. (2016): Applied the method to healthcare IoT, minimizing latency in secure device communication. While efficient for frequent device changes, it didn't fully address extreme resource constraints in wearables.

Li et al. (2017): Combined B-Tree GKA with ECDH to improve scalability and reduce computation time, but complexity hindered adoption in resource-limited healthcare environments.

Gupta et al. (2019): Used B-Tree GKA with lightweight cryptography for secure multicast in hospitals, effective for small setups but lacking large-scale scalability.

Kim et al. (2020): Targeted smart city IoT scalability, managing key updates efficiently in large networks, though performance depended on stable connectivity.

Al-Kuwari et al. (2021): Optimized the structure for energy efficiency in highly constrained devices, trading off some security robustness—making it less ideal for sensitive healthcare systems.

Yao et al. (2022): Merged B-Tree GKA with ECDH and homomorphic encryption to boost scalability and privacy in industrial IoT. Security improved, but processing demands limited use in low-power devices.

Zhao et al. (2023): Developed an adaptive B-Tree GKA that clusters devices by behavior, enhancing rekeying in

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mobile healthcare environments. Complexity posed challenges for large-scale deployments.

Wang et al. (2024): Integrated blockchain with B-Tree GKA for decentralized, privacy-preserving healthcare communication, but blockchain overhead reduced suitability for constrained devices.

Ahmed et al. (2024): Proposed a lightweight version for healthcare IoT to lower energy use and streamline rekeying, effective in small deployments but with limited security for large networks.

Limitations and Challenges

While B-Tree-based GKA offers numerous advantages for securing group communication in IoT environments, several challenges remain:

- **Scalability**: As the network size increases, managing the B-Tree structure becomes complex, especially in environments with frequent device mobility.
- **Energy Consumption**: Although B-Tree GKA can reduce the overhead of rekeying, energy consumption remains an issue in resource-constrained devices such as medical sensors and wearable devices.
- **Computational Overhead**: Integrating additional security measures such as blockchain or homomorphic encryption, while enhancing security, often introduces significant computational overhead, limiting the applicability in low-power IoT devices.

Conclusion

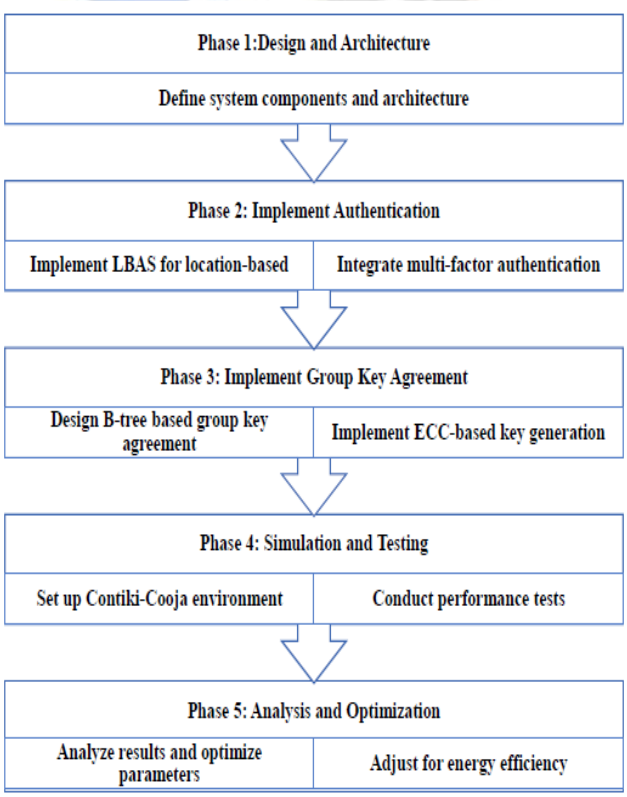
B-Tree-based Group Key Agreement (GKA) has proven to be an effective method for managing secure group communication in dynamic IoT environments. Its hierarchical structure minimizes rekeying overhead, making it ideal for environments where devices frequently join or leave the network, such as healthcare IoT systems. However, challenges related to scalability, energy consumption, and computational overhead remain, requiring further optimization for broader IoT applications. Future research should focus on enhancing the efficiency and scalability of B-Tree-based GKA while addressing the resource constraints of IoT devices, particularly in sensitive environments like healthcare.

VI Research Gap

Despite advancements in IoT security, gaps persist, particularly in balancing security with energy efficiency. Large-scale healthcare IoT systems require scalable solutions that minimize computational overhead. Future research should focus on optimizing encryption techniques, refining key management strategies, and enhancing authentication protocols to address these challenges effectively.

VII Proposed Methodology

The proposed research focuses on developing scalable, energy-efficient, and computationally efficient cryptographic protocols that can adapt to the dynamic nature of healthcare IoT systems. The following Flowchart is proposed to develop scalable, energy-efficient, and computationally efficient cryptographic protocol for the research.



Implementation Flowchart of proposed method

CONCLUSION

Although B-Tree-based Group Key Agreement (GKA) and Location-Based Authentication (LBA) have advanced considerably, their application in IoT, especially in healthcare still faces notable gaps. Challenges such as scalability, energy efficiency,

computational overhead, and efficient dynamic rekeying need to be resolved for broader adoption in sensitive healthcare settings. Future work should prioritize the design of cryptographic protocols that are scalable, energy-efficient, and lightweight, while adaptable to the dynamic nature of healthcare IoT. Overcoming these issues will enable secure, efficient operation of healthcare IoT systems, safeguarding patient data and reducing the strain on resource-limited devices.

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