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Security Challenges in Quantum Key Distribution and Robust Cryptographic Methods for Wireless Body Sensor Networks: A Comprehensive Survey

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ABSTRACT

Wireless Body Sensor Networks (WBSNs) and Quantum Key Distribution (QKD) provide distinct yet interrelated possibilities and challenges in the quickly changing field of network safety. This review explores the safety concerns that come with quantum key distribution (QKD), emphasizing problems like quantum surveillance, protocol weaknesses, and the necessity of workable application solutions. Simultaneously, it examines the strong cryptographic techniques necessary to protect Wireless Body Sensor Networks, which are becoming increasingly important in applications related to individual tracking and medicine. Everyone investigates new approaches, assesses their efficacy, and suggests future lines of inquiry to tackle the critical safety concerns of body networked sensors and quantum messaging. By strengthening the security architecture in both domains, this integrated strategy seeks to provide reliable and solid interaction networks against ever-changing threats.

Keywords: *Quantum Key Distribution; Wireless Body Sensor Networks; Network Security; Cryptographic Methods; Quantum Communication; Security Challenges; Eavesdropping; Protocol Vulnerabilities; Robust Encryption; Healthcare Security; Personal Monitoring Systems; Cryptographic Protocols*

1. INTRODUCTION

Thousands of interactions occur daily over the internet worldwide. Many of these online transactions involve confidential information that must remain private. Therefore, both the financial transaction and the individual performing it must be verified. Researchers in the field of security, utilizing cryptography, have developed several innovative approaches to ensure the safety of these transactions. Cryptography-based methods provide a secure means of communication by masking ordinary text messages. Since sensitive information is stored on fast communication networks, such as servers on the World Wide Web, it is crucial to enhance their security, along with faster processing and greater adaptability [1]. As a result, researchers have shifted from public key cryptography to symmetric cryptography. ECC method is preferred over other public key algorithms for internet-based encrypted communication because it offers faster computations and requires fewer resources for transmission. Due to its advantages in processing speed and key size, ECC can provide effective security in both resource-constrained environments and those with abundant resources, such as high-performance networks and internet communications [2]. Wireless networking equipment, such as routers and Ethernet switches, often play a key role in maintaining network security. All wireless network-based communications, especially those conducted via ad hoc and sensor networks, are encrypted. [3] This encryption is also responsible for organizing the data collected at a central location for analysis and storage. The multifunctional sensor nodes that comprise Wireless Sensor Networks (WSNs) are typically small in size and have enhanced communication capabilities over short distances. Today, WSNs are used for various applications, including forest fire monitoring, military surveillance, ecological monitoring, building security systems, and tracking patient health in the healthcare sector [4]. Essential security features required in WSNs include confidentiality, data integrity, availability, node autonomy, secure information transmission, time synchronization, and authentication [5].

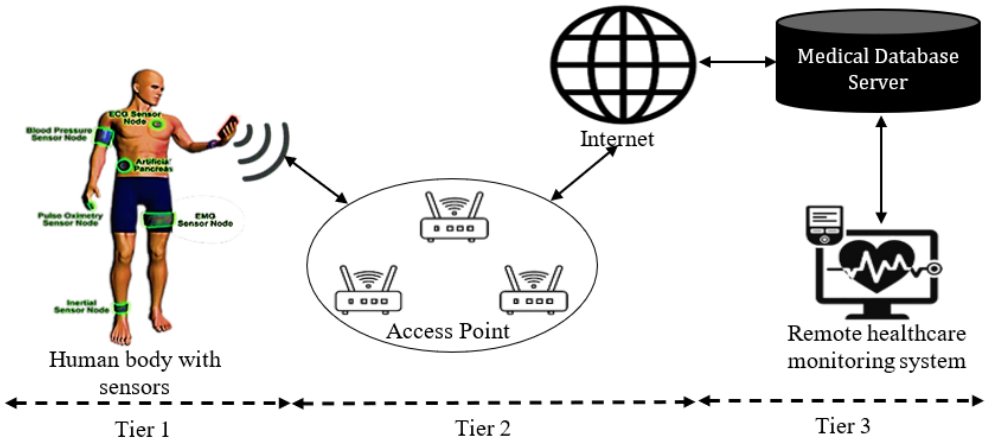

Figure 1: Architecture of WBSN

The WBSN is designed to monitor physiological signals and biological activity in individuals by gathering sensor nodes that are implanted or worn on the body. In the era of modern innovation, WBSN provides an advanced system for monitoring the health of individuals both inside and outside medical facilities. These body sensors are battery-powered and equipped with capabilities for detecting, processing, transmitting, and monitoring body temperature, heart rate, ECG and EEG signals. The collected data is then wirelessly transmitted to the healthcare provider for further analysis [6]

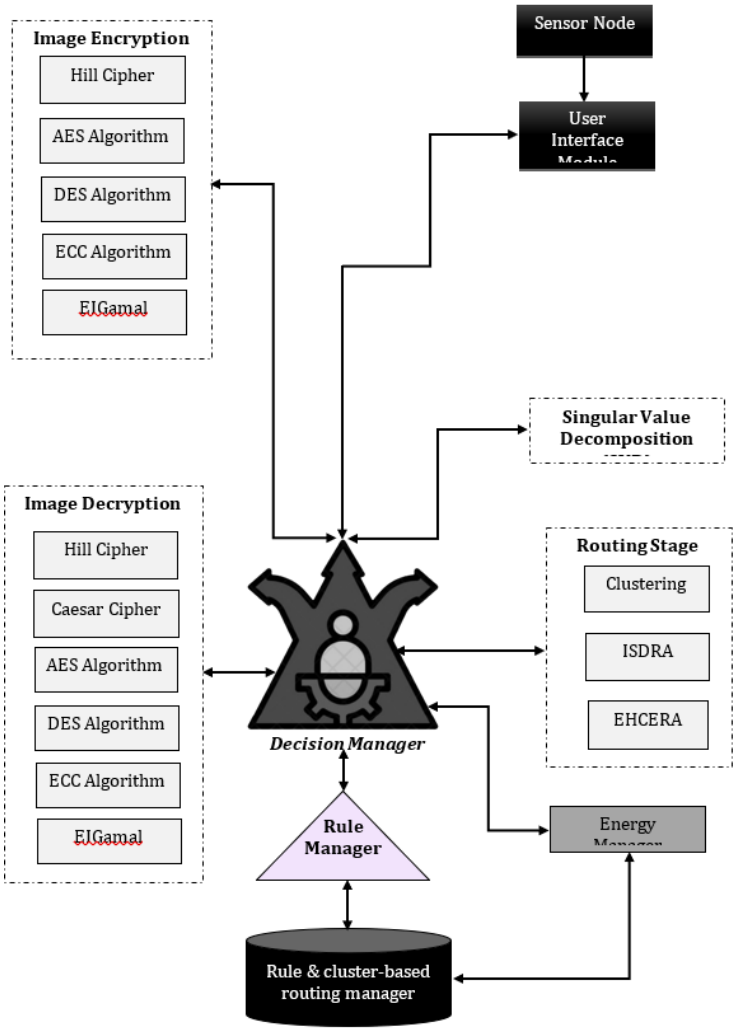

Figure 2: Secure data communication system architecture

The purpose of WBSN is to gather information from human body monitors and to connect with people wirelessly via connection points, individual computers, and medical record databases. The body detectors implanted into humans make up the initial tier of WBSN. These devices pick up electrical and mechanical signals from the body of a person, process them into digital format, and then immediately transfer them to the subsequent tier. After receiving and processing information from the sensors, the second layer sends the outcomes of the processing to the third tier [7]. Medical professionals occupy the third rank. For wireless sensors to communicate, a new secure transmission of information paradigm that makes use of cryptographic algorithms is advised. The proposed safety algorithm's whole architecture is depicted in Figure 2. There are 10 main operational mechanisms in the design. These include routing, energy management, decision-making, rule management, image data encryption, image decoding, single-value decomposition, and the user experience component [8].

1.1 Problem Statement

Rapid advancements in WBSNs have transformed medicine by making it possible to monitor vital signs continuously and provide remote patient care. Nevertheless, there are significant dangers when WBSNs are integrated with private health information. It is difficult for conventional cryptography techniques to offer sufficient defense against new attacks, especially in the setting of quantum computing. To ensure secure communication, QKD leverages the concepts of quantum physics and presents a possible approach. There are several obstacles to overcome before QKD can be implemented in WBSNs, such as vulnerability to eavesdropping,weaknesses in protocols, and the requirement for strong cryptographic techniques that can fend off both conventional and quantum assaults. The objective is to provide strong cryptography techniques that improve WBSN assurance and reliability and guarantee the safety of critical patient information from existing and upcoming cyberattacks.

1.2 Motivation

Attackers can add, remove, or alter detected information during this transfer. A deadly circumstance, such as passing away, will result from physiological modifications to the human body. Clinical information can be added, removed, or modified as it is being transmitted over WBSN.In wireless body network sensors, there are safety concerns such as loss of information, masquerade attacks, transmission problems with secret keys, illegal access, and loss of information confidentially. Since WBSN medical diagnoses must be made accurately, confidentiality of information is crucial to each study. A broad focus is placed on safety issues such as secret key creation and transportation, authorization, and secrecy in the proposed study endeavor. The newest innovations in remote medical diagnosis and administration are WBSN. It has a lot of promise to keep the doctor updated in real-time on the condition of the patient. Wireless connectivity is used to exchange data from tiny implanted or wearable body sensors that measure physiological characteristics and emotions in people. Human body parts are equipped with wireless physiological sensors. For a doctor to determine the condition of an individual remotely and prolong their life, accurate information from WBSNs is required. The physician's remote therapy may be impacted if there are any malicious assaults or updates made to the remote body sensor information. Erroneous body information from sensors could contribute to incorrect illness evaluation and therapy. The main concerns with wireless body networks of sensors in healthcare settings are privacy and safety.

2. CRYPTOGRAPHY

The investigation and implementation of different methods for encryption and decryption to render data kept in storage devices or sent over networked computers incomprehensible to anybody other than the intended recipients. The goals of cryptography extend beyond encoding messages and decoding. Safeguarding applications that demonstrate required for increased security of data has also been a priority in the past few years [9]. When enabling secure interaction between two network subscribers, Alice and Bob, in the presence of an intruder named Eve, the security of data has four main goals. They are non-repudiation, authorization, confidentiality of information, and secrecy. These may be accomplished by creating stronger keys and effective encryption methods. The amazing craft of constructing codes for concealed data is called encryption. It may be used to satisfy basic safety requirements such as network security and privacy. Cryptographic procedures are depicted in Figure 3. It is made up of data encryption, decryption, public and private keys, encrypted data, and transparency [10].

2.1 Role of Keys in Security Cryptography

Since keys are crucial to cryptography, the process of generating them is crucial. Furthermore, the encryption keys can be utilized to preserve secrecy. A substantial amount of information secrecy may be achieved with asymmetric cryptography. In cryptography, the ideal key size is necessary to both minimize complexity and increase safety. A decryption operation will not succeed if any other kind of password is used. The safety level offered by cryptography may be increased by using various key sizes. In this case, the sender generates the secret key. An ideal key administration system should offer a safe means for both the sending party and the recipient to exchange private keys [11].

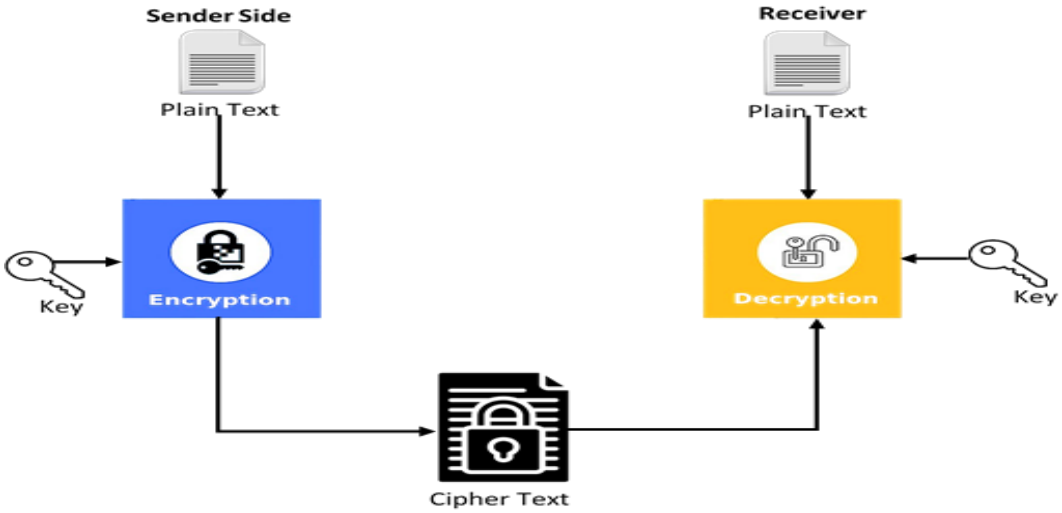

Figure 3 Cryptography process

2.2 Cryptographic Key Types

In cryptography, there are two kinds of keys: secret keys and publicly available keys. The same key is used in symmetrical key cryptography for both encrypting and decoding. Two different kinds of keys are used in public key cryptography: public keys and private keys [12].

2.2.1 Symmetric-Key based Cryptography

Modulogroups and sectors were key components in the creation of mathematical algorithms for cryptography. For instance, the Advanced Encryption Standard (AES) symmetrical key cryptography technique makes use of the Galois field shown in Figure 4.

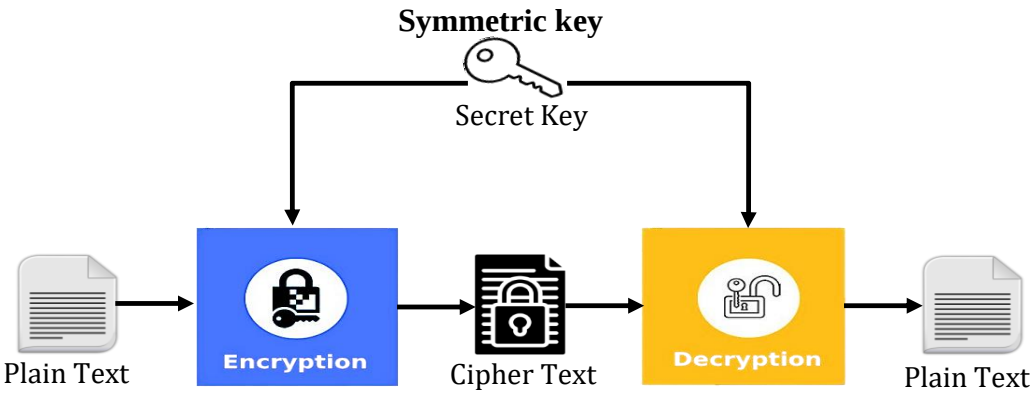

Figure 4: Symmetric key encryption and decryption

2.2.2 Public-key cryptography using Asymmetric keys

The primary drawback of symmetrical key encryption is the requirement for both the sender and the recipient to have a secret agreement on the key$K_e$and K_d. One of the major drawbacks of symmetrical exchange of keys approaches is this. Each group of talking participants requires a key for safe interactionis the primary disadvantage of this secured key method. Consequently, the number of keys will be in the order of n^2 if there are 'n' individuals interacting over the systems [13]. Every entity in this room has to retain the O(n) keys to safely communicate with other involved entities. But in practical situations, an entity won't speak with every other talking entity on the network. Consumers must memorize a large number of keys when using symmetric key methods. Either a public-key method or an asymmetric-key protocol can effectively tackle this issue of encryption. Every object in this protocol will select a key pair.. The fact that $K_e$and $K_d$the earlier method is used to create cipher text (C) from plain text messages (M) and the latter is utilized to create M from C makes it clear that they are somewhat inverses of one another. This is how safety systems, as seen in Figure 5 employ the mathematical aspects of public key cryptography [14].

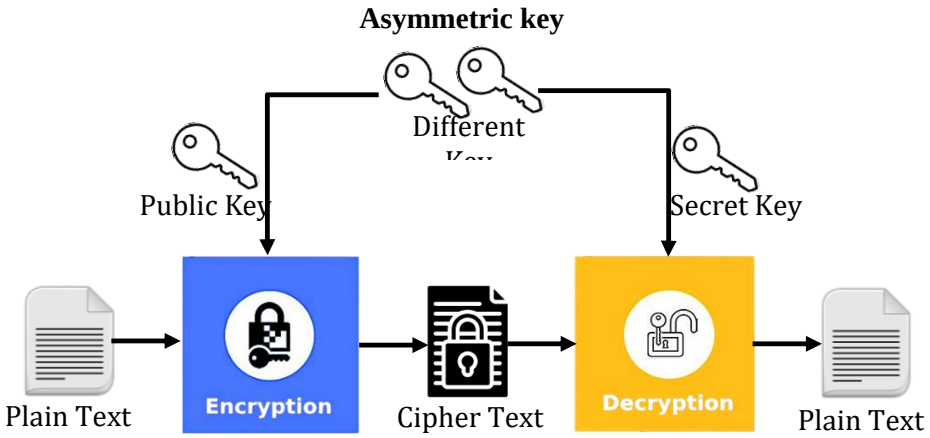

Figure 5: Asymmetric key encryption and decryption

The three most important developments in cryptography with public keys are the theory of grouping, Euler's theorems, and Fermat's theorem. ElGamal cryptography, the RSA technique, and the Diffie-Helman Key Exchange, also referred method are the three most significant methods in cryptography with public keys. ECC is employed in the majority of software programs because of its greater safety and reduced key size. Based on the RSA method's difficulty, the ECC method offers far stronger and greater safety. In this thesis, new methods utilizing Euler's phi function, beta functions, gamma functions, and ECC are proposed [15]. To demonstrate the uses of the proposed ECC-based encryption methods, it also suggests a cluster-based safe transportation mechanism shown in Table 1.

Table 1: Related works based on cryptography

Title	Year	Methods Used	Advantages	Limitations
A Survey on Cryptographic Algorithms for Data Security in Cloud Computing [15]	2023	Symmetric Encryption, Asymmetric Encryption, Homomorphic Encryption	High-level security for cloud data, adaptable to different cloud services	Computational complexity, performance overhead
Lightweight Cryptography for IoT Devices: A Comparative Study [16]	2023	Lightweight Block Ciphers, Stream Ciphers, ECC	Energy-efficient, suitable for resource-constrained IoT devices	Limited key size, potential vulnerability to quantum attacks
Quantum-Safe Cryptography: A Survey of Approaches and Challenges [17]	2024	Lattice-Based Cryptography, Code-Based Cryptography, Multivariate Cryptography	Resistant to quantum attacks, future-proofing for post-quantum era	Larger key sizes, slower performance compared to classical cryptography
Elliptic Curve Cryptography: A Comparative Study of Recent Developments [18]	2023	ECC Variants, Hybrid ECC Algorithms	Faster computations, smaller key sizes, reduced resource usage	Potential susceptibility to side-channel attacks
Blockchain-Based Cryptographic Techniques for Secure Transactions [19]	2023	Blockchain, SHA-256, Public Key Infrastructure (PKI)	Decentralization, immutability of records, enhanced transaction security	High energy consumption, scalability issues in blockchain
Homomorphic Encryption for Secure Data Analysis in Healthcare [20]	2024	Fully Homomorphic Encryption (FHE), Partially Homomorphic Encryption (PHE)	Enables data analysis on encrypted data without decryption, privacy-preserving analytics	Extremely high computational overhead, impractical for la

2.3 Quantum Cryptography

Quantum cryptography (QC), as opposed to existing encryption techniques allows for the safe sharing of secret keys between two individuals, and even passively eavesdropping across a communications channel. In contrast to existing encryption, this may rely on quantum physics' instability concepts. QC has limitless processing capacity and methodologies that are governed by physical law. These characteristics provide the communication entities with a reliable allocation of keys mechanism [21].

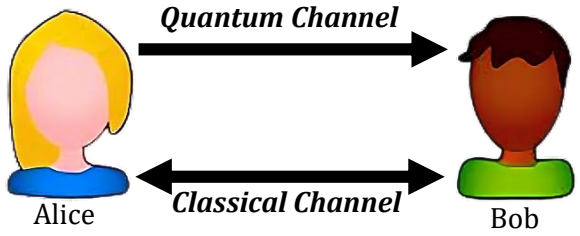

Figure 6 Quantum key generation communication channel

2.3.1Photon Polarization

Light may move at right angles to its passage in all directions. Polarized illumination, however, can only move in a single direction.

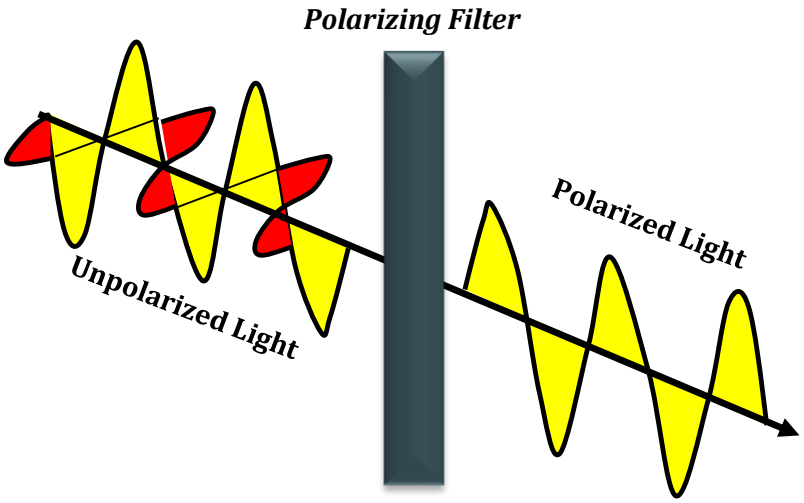

Figure 7 Polarization process

In Figure 7, the polarization process is diagrammed. Discrete quanta are used to propagate light waves. We refer to these quanta as photons. Two types of polarization filters are distinguished. Diagonal polarization filter and Rectilinear polarization filter

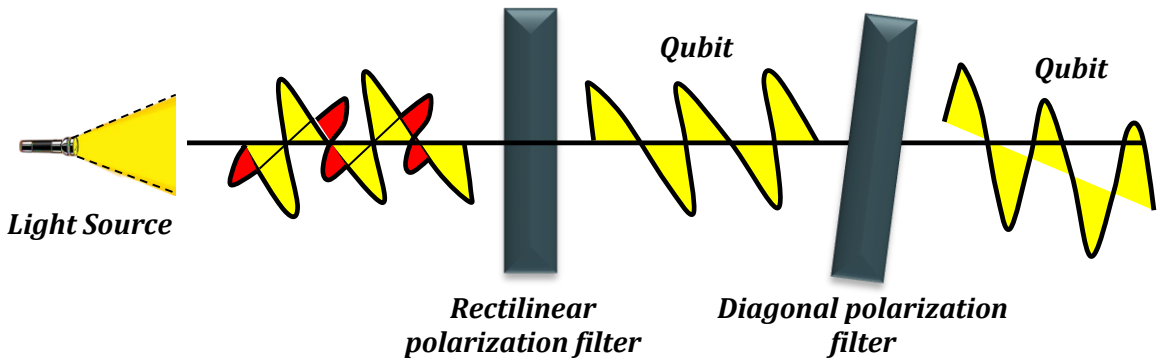

Figure 8 Photon Polarization types

Lighting sources produce light waves, as seen in Figure 8. Qubit is produced at a 90-degree angle when light sources are directed through a rectilinear polarizing filter. Qubit is formed at an angle of 450 if the light origin propagates into the diagonal polarizing filter [22].

2.3.2Qubit Generation

In this case, communication participants without direct mode exchange the secret key. Sender and receivers share confidential data using qubits rather than zeros and ones, attackers are unable to predict the style of communication or the data that will be sent. Quantum encryption prevents information from being updated or copied. For this purpose, quantum cryptography is used currently to safeguard health information [23].

3 Key generation better performance

While secure communication is a major concern for any distant internet connection, body sensor networks—particularly those used in clinical settings—need to take security seriously. The generation and dissemination of keys, illegal availability, message disclosure, communication alteration, hacking attempts, and malicious actions are the safety risks associated with WBSNs. Unauthorized users may surely access health information in WBSN, and hackers can modify data. Clinical information production, deletion, and alteration require a strict security element. One of the proposed system's limitations is the unsecured key mobility [24]. A novel key exchange method for secure communication in WBAN was proposed. Before communication, the proposed approach tested and confirmed the physiological characteristics of the receiver and transmitter devices. This approach secured communications in the WBAN within a predetermined time frame by utilizing pre-knowledge from prior sessions. This procedure has the benefit of using the knowledge from the prior session for the crucial agreement. The capability can prevent eavesdropping attempts and shorten the time needed to generate the secret password [25].

The writers had not given the possibility of lowering the sensor interaction rate any thought. Carried out security analyses based on probabilistic approaches after discussing the QKD method and its safety against assaults. The authors described how a series of quantum photons is used to encrypt random values. The proposed solution demonstrated the superior security of the QKD approach over the existing approach. The potential distance for information to travel between the sender and the recipient is offered by this approach. This scheme's shortcoming is that it can only send the secret quantum key across distant locations. The proposed solution did not incorporate the different safety analyses, such as a resend attack or a man-in-the-middle assault, according to the researchers. A genetic-based approach for safeguarding information in wireless body sensor networks has been proposed [26]. The proposed plan performs exceptionally well in terms of safeguarding information. After obtaining the patient's information, our approach produced a lightweight encryption scheme based on genetics. The proposed encryption method includes string visualization, amino acid table, crossing replacement box, and mutation [27].

Data is sent between sensors using MQTT. These days, the transmission of information in the Internet of Things apps uses it. Overall, telemetry-style data communication is possible. The protocol at issue uses a small bandwidth for communication. This scheme's benefit is its key generation method, which requires extremely few computations and fewer stages. This scheme's flaw is that it doesn't analyze the many types of assaults in the WBSN. A novel technique for Private Information Retrieval (PIR) from databases was presented. PIR is an interface for database queries. It is employed to provide an individual with access to a certain database entry [28]. The information center is not aware of the user's query. It featured randomization between the people conversing and long-shared secret keys constructed using quantum cryptography. Any outside eavesdropper can be detected using the proposed approach. QKD is the technique's merit. In other words, provides PIR with star topology in a network its keys. The hub establishes a physical link between consumers and information centers. The framework is not vulnerable to any assaults. The work's computational cost is a shortcoming. The creation of a traceable, anonymous participation approach is the work's achievement. The traceability of the corresponding node sensors was made possible by this effort.This proposed scheme's shortcoming is its inadequate performance when compared to existing public-key cryptography methods.

To closely track a satellite healthcare system, presented a novel four-tier design for WBAN. They determined safety needs and difficulties for every component of the WBAN. Tier-1, tier-2, tier-3, and tier-4 WBSN levels are used in this study. In layer 1, the human body is home to both the sender and the recipient. At least one of the parties who communicate in tier 2 communications is an inside member of the body of a person. In tier 3, a human body contains no less than one of the communication technologies. Tier 4 refers to any communications that take place outside of the human body. Concentrated on using WBAN to safely transfer information from wearable devices to external networks. The researchers presented a one-time pad method for key creation dubbed quantum key transmission, which may transport knowledge from one device to the next by utilizing quantum features. This method ensures that during delivery, the key cannot be changed or intercepted [29]. Table 2 summarizes recent developments in key generation for cryptography, focusing on the methodologies, benefits, and drawbacks associated with each approach

Table 2: Related works based on Key Generation

Title	Year	Methods Used	Advantages	Limitations
Efficient Key Generation Using Elliptic Curve Cryptography for IoT Devices [30]	2023	Elliptic Curve Cryptography (ECC)	Smaller key sizes, faster key generation, suitable for resource-constrained devices	Susceptibility to side-channel attacks
Quantum Key Distribution for Secure Communication: A Survey [31]	2024	Quantum Key Distribution (QKD), BB84 Protocol	Unconditional security, resistant to quantum computing attacks	High implementation cost, sensitivity to environmental factors
Lightweight Key Generation Techniques for Resource-Constrained Networks [32]	2023	Lightweight Cryptography, Physically Unclonable Functions (PUFs)	Energy-efficient, low computational overhead, suitable for IoT and WSNs	Limited key length, potential vulnerability to certain physical attacks
Advanced Key Generation Mechanisms for Post-Quantum Cryptography [33]	2024	Lattice-Based Cryptography, Ring Learning With Errors (Ring-LWE)	Quantum-resistant, highly secure, scalable for future-proof cryptography	Larger key sizes, increased computational requirements
Blockchain-Based Key Generation for Decentralized Applications [34]	2023	Blockchain Technology, Distributed Key Generation (DKG)	Decentralized, tamper-resistant, enhanced security for distributed systems	Scalability challenges, high energy consumption in blockchain networks
Entropy-Based Key Generation for Secure Cloud Storage [35]	2023	Entropy Harvesting, Random Number Generators (RNGs)	High randomness, strong security guarantees for cloud storage	Dependency on entropy sources, potential weaknesses in RNGs
Hybrid Key Generation Techniques Combining Classical and Quantum Cryptography [36]	2024	Hybrid Cryptography, Quantum Key Distribution (QKD), Public Key Infrastructure (PKI)	Combines benefits of classical and quantum cryptography, increased security, future-proofing	Complexity in implementation, requires integration of quantum and classical systems

3. AUTHENTICATION

Authentication is a crucial component in ensuring secure communication and data protection in various technological systems. Recent advancements in authentication techniques aim to enhance security and address emerging threats. Table 3 summarizes recent research papers on key generation and security methods in cryptography and wireless networks.

Table 3:Related works based on Authentication

Year	Title	Methods Used	Advantages	Limitations
2021	Safe and Anonymous Mutual Identification Technique (SAMAKA) [37]	Hash and XOR operations, mutual authentication, key collaboration	Thorough evaluation of safety features against WBAN-specific attacks, effective session key agreement	Time requirements for the cryptographic procedure not examined

2021	Novel Technique for Security in Wireless Sensor Networks (WSNs) [38]	Anonymous authentication method, large information ecosystem	Effective ideal forward confidentiality, suitable for large-scale information environments	Does not address other potential security risks
2020	Secure Roaming Services for Mobile Users Using Lattice-Based Cryptography [39]	Lattice-based cryptography, mutual authentication	Lightweight, quantum-resistant roaming verification technique	Minimal improvement in international service effectiveness for mobile users
2019	Privacy Protection in Body Area Networks (BANs) [40]	Alternative authentication process for inter-sensor communication	Protects confidentiality and security of data, provides formal safety certification	Less efficient compared to other algorithms
2018	Hybrid Wireless Body Area Network (WBAN) for Fitness Tracking [41]	Elliptic Curve Diffie-Hellman (ECDH) cryptography, hashing functions	Secure cloud transmission, suitable for both wired and ad hoc networks	
2018	Cost-Effective Wireless Sensor Devices for Physiological Monitoring [42]	Low-energy wireless body area network, improved key management methods, authentication strategy versions	Simple and sophisticated key management, secure method of key generation and validation	High resource utilization
2017	Medical State Monitoring Using Wireless Body Area Networks (WBANs) [43]	MAC standards, two-layered taxonomy for MAC protocols	Reliable information and energy usage	Slot assignment issues, complexity in channel access architecture
2016	Three-Factor Authentication for Cloud Communication of Sensitive Health Information [44]	Biometrics, smart cards, credentials	Prevents offline password guessing attacks and impersonation during enrollment	No comparison of time requirements with other existing systems
2016	Bluetooth-Based Body Area Network System for Quality of Service and Adaptability [45]	Priority-based adaptive MAC technique, traffic priority-based time slot allocation	Reduces WBAN latency, avoids information collisions, minimizes packet delays, and lowers energy consumption	Minimal number of slots may impact performance, lacks security and privacy considerations
2015	Hybrid Encryption Technique for Online Communication [46]	Combination of two distinct encryption algorithms	Hybrid encryption technique that prevents deciphering from ciphertext, optimizes storage capacity	

4. CONFIDENTIALITY

Encryption and decryption procedure should be carried out with an offline key. The use of encryption, decoding, and creating keys are the three stages of the RSA. The prime number of RSA and its calculation are readily cracked by adversaries. To

improve the security of the RSA method, the inventors paired it with either the Diffie-Hellman or ElGamal algorithms. Rather than using two numbers that are prime, three or four prime numbers are needed to construct the RSA key value. Table 4 summarizes the key aspects of each paper, including methods used, advantages, and limitations.

Table 4: Related works based on Confidentiality

Title	Year	Methods Used	Advantages	Limitations
Unveiled a novel RSA technique for safe information transfer [47]	2021	RSA with three keys (Server's public key, Server's private key, User's private key)	Enhanced security with three keys; longer time to crack the cryptosystem	Sluggish processing speed; complexity in key creation, encryption, and decryption
Concentrated on implementing an RSA method variant in wireless sensor networks [48]	2021	RSA with Adhoc On-Demand Vector Routing (AODV) protocol	Reduced RSA complexity; improved safety for WBAN standards	Weakened by key creation, encryption, and decryption stages; computational difficulty
Preprocessed symmetric RSA (PSRSA) for wireless body area networks [49]	2021	Symmetric RSA with lower key sizes	Reduced processing; meets WBAN safety standards; multi-layer processing with RSA	Computational difficulty
Improved RSA for safe transfer of information in mobile telephony and healthcare [50]	2021	RSA combined with Diffie-Hellman or ElGamal; use of three or four prime numbers	Improved security with multiple keys; lightweight encryption algorithms	Complexity of using multiple keys; difficulty in processing
Examined security specifications, vulnerabilities, and countermeasures for wireless body area networks [51]	2020	RSA with n prime numbers and multiple public keys	High security through discrete logarithms; unpredictability of private and public keys	High communication overhead; lack of time measurement and security analysis comparison
New security protocol for m-Healthcare emergencies [52]	2020	Privacy-Preserving Scalar Product Computation (PPSPC) and attribute-based access control	Enhanced manageability of attacks; secure PHI communication	Lengthy processing time; could impede data transmission

5. WORKS ON SECURE ROUTING FOR ENERGY EFFICIENCY

Established security objectives for routing in Wireless Sensor Networks (WSNs) and demonstrated methods to identify attacks resilient to threats such as HELLO floods and sinkholes. They also described various crippling attacks. They developed and introduced an innovative method for determining network topology that allows the sink node to gain a shared understanding of the network architecture without revealing its location. Their approach employs an integrated cryptographic method to generate new data packets randomly across continuous networks, helping to defend against attacks targeting network traffic that attempt to infer the node's incorrect position. Protocols utilized only basic symmetric cryptography.

A novel model was introduced, and the outcome is based on heterogeneous sensor networks. This procedure was designed to achieve a higher level of security. They developed a new routing-driven approach to key management in their model, which established shared keys for intercommunication. They designed a key management system for sensor nodes in WSNs using (ECC. Approach outperformed others in terms of sensor node energy efficiency, data communication overhead, and sensor node security. By ensuring a multipath routing structure, they established and expanded a novel routing protocol that enhances reliability and quality. Their protocol operates as a distributed verification method that does not require base station verification.

They analyzed an optimal problem involving multipath routing using actual data and a detailed structure. Their analysis aimed to improve network lifetime, network security, and energy consumption. They implemented an energy-efficient and

secure disjoint routing algorithm to transfer data from the WSN's source to its destination. As a result, they improved network longevity and enhanced detection of both multiple and single black hole attacks. Their technique for concealing secret messages focuses on secure communication mechanisms to facilitate cooperative multimedia data dissemination in sensor networks, thereby mitigating various active external attacks. Their approach integrates data assurance analysis at the physical layer with cryptographic techniques to enhance the security of the data transmission process. This method significantly improved accuracy while effectively detecting compromised nodes.The technology for routing was developed and refined. Through their precise picture routing, they enhanced a secure routing protocol based on Geographic Secured Routing, which protects data by implementing an energy-efficient authentication method. Their authentication process uses the SHA-3 algorithm rather than other user-defined methods. This approach has demonstrated effectiveness in terms of security.To address security compromises, they devised an innovative method to access data and present a probabilistic and multivariate polynomial secure routing system. They proved a significant reduction in the probability of sensor-based attacks. They developed and proposed a trust-based, energy-efficient routing strategy to facilitate efficient data transfer in WSNs. A new secure routing protocol was created and implemented, featuring distributed key generation over a new signature system, which allows any node to obtain a secret key. In the final stages, they demonstrated that their technique effectively secured mobile networks through a re-authentication approach using an authentication system. They conducted a comparative study between conventional protocols and their proposed protocols for node authentication, showing that their approach provided superior security with lower overhead.

Research Gap

While WBSNs have gained significant attention for their potential in healthcare applications, the security mechanisms currently in place are often inadequate to address the sophisticated threats posed by both classical and quantum attacks. Traditional cryptographic methods are becoming increasingly vulnerable, particularly with the advent of quantum computing, which can potentially break existing encryption schemes. Although QKD has been proposed as a secure communication method leveraging quantum mechanics, its implementation in WBSNs is still in its infancy.

The existing literature primarily focuses on the theoretical aspects of QKD and its application in general communication networks, with limited research addressing the unique challenges of integrating QKD into WBSNs. Specifically, issues such as the energy constraints of sensor nodes, the mobility of patients, and the varying data transmission rates in WBSNs are not adequately addressed in current QKD frameworks. Moreover, there is a lack of comprehensive studies that explore the development of robust cryptographic methods tailored to the specific requirements of WBSNs in a quantum computing era.

- Inadequate Security Mechanisms: Existing security protocols for Wireless Body Sensor Networks (WBSNs) are insufficient to combat sophisticated threats, especially those emerging from quantum computing.
- Vulnerability of Traditional Cryptography: With the advent of quantum computing, traditional cryptographic methods are increasingly at risk, as quantum algorithms can potentially break current encryption techniques.
- Limited Application of QKD in WBSNs: While Quantum Key Distribution (QKD) offers a promising solution for secure communication, its integration into WBSNs has not been extensively explored, leaving a gap in practical implementation.
- Specific Challenges in WBSNs: Unique challenges such as energy constraints, patient mobility, and varying data transmission rates in WBSNs are not adequately addressed by current QKD frameworks.
- Lack of Tailored Cryptographic Solutions: There is a need for the development of new cryptographic methods specifically designed for WBSNs to ensure security, efficiency, and resilience against both classical and quantum threats.
- Scarcity of Comprehensive Studies: Few comprehensive studies focus on the intersection of QKD and WBSNs, highlighting the need for research that addresses both the feasibility of QKD implementation and the development of robust cryptographic solutions for these networks.

This research gap underscores the need for focused studies that not only examine the feasibility of implementing QKD in WBSNs but also develop and evaluate new cryptographic methods that can offer enhanced security, efficiency, and resilience against both classical and quantum threats in these specialized networks.

6. CONCLUSIONS

The research underscores that while quantum key distribution offers a promising solution for achieving theoretically unbreakable encryption due to its quantum mechanical principles, practical implementation faces significant hurdles. These include high costs, sensitivity to environmental factors, and complex technology requirements. The survey emphasizes that despite these challenges, QKD remains a robust approach for securing communication against future quantum computing threats.In the context of WBSNs, the survey identifies several security challenges such as limited resources, energy constraints, and the need for lightweight cryptographic solutions that do not compromise performance. The research indicates that while various cryptographic methods have been proposed to enhance security in WBSNs, including elliptic curve

cryptography and hybrid encryption techniques, issues like key management, data integrity, and protection against physical attacks persist.Overall, the survey suggests that a comprehensive approach integrating advanced cryptographic techniques with practical implementation strategies is essential for addressing the security needs of both quantum key distribution systems and wireless body sensor networks. Future research directions include improving the efficiency and scalability of QKD systems, developing more resource-efficient cryptographic methods for WBSNs, and exploring hybrid approaches that leverage both quantum and classical cryptographic techniques to provide robust security in diverse applications.

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