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Research Article

Advancing Security and Efficiency in IoT Healthcare Applications with Challenges Benefits and Latency Reduction Techniques

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ABSTRACT

With the expansion of the Internet of Things (IoT) and cloud computing, conventional reliance on centralized cloud data centres for the storage, analysis, and real-time processing of vast data volumes presents significant challenges. This is particularly applicable to the elevated latency and stringent security demands necessary for real-time IoT healthcare applications. Critical and time-sensitive applications, including e-healthcare, telemedicine, and robotic surgery, necessitate ultra-low latency and stringent security measures. Suboptimal processing, connectivity, and networks impede the performance of these applications. Moreover, conventional cloud designs frequently fail to provide the necessary Quality of Service (QoS) for IoT healthcare systems. Consequently, this essay also explores latency reduction and security improvement techniques in IoT healthcare focusing on the need for information transmission in the respective areas. It wishes to list the first principles for approaches that reduce latency and protect communications, and computational architectures that can operate with such systems. It also explores the features that are crucial for understanding latency and security, as well as comparing several methods of addressing latency reduction and improvement in security alongside their effectiveness. It critically assesses previous approaches, identifies gaps in the literature and emphasizes unanswered questions in the study that may be useful in other works in this field. This research incorporates these findings into propelling concepts relative to IoT device connection and enhancing general paradigms relating to the better employment of healthcare applications. These findings support the need to design future IoT healthcare systems that will be latent sensitive, security-enhanced, and high-performance systems due to emerging characteristics of IoT in healthcare.

Keywords: IoT Healthcare Applications; Latency Reduction; Security Enhancement; Quality of Service (QoS); Cloud Computing Integration

INTRODUCTION

IoT emerged in 2020 witnessing unprecedented growth where billions of devices were connected across the world. This extensive network produced a tremendous amount of data, which is estimated to be about 507.5 ZB per year [1], [2]. Although this expansion gives credit to IoT as a revolutionary technology, it reveals increased complexity challenges, especially in handling real-time data services. The large volumes of data that were transmitted

overwhelmed computation and transmission capacities resulting in issues of efficiency, reliability as well and security.

The effect of this is most keenly felt in cloud-scaled services where the timeliness of processing streaming data is of paramount importance. With the growth of data volumes, the opportunity for errors was higher, which was expressed in packet loss and transmission delays. All of these endangered the Quality of Service (QoS) perceived by the end-users [3]. Challenges such as long transmission delays and reduced service quality were observed to be effective issues of IoT in applications, especially in areas where high response is expected such as healthcare. However, the emergence of a large volume of data pressured extant cloud computing systems, which in turn increased latency and synchronization challenges [4].

Another impact of high latency was synchronization or rather the lack of it between clients' requests and servers' responses which delayed key IoT services. The many interruptions and overloads of networks on IoT devices and the cloud servers made it worse, increasing service delays. Real-time applications suffered most from this because delay was now the main challenge to efficient service delivery. Also, the number of gateway nodes needed to forward the collected data also depends on the distance between IoT devices and their destination, which also augments system complexity and latency [5].

Overcoming the problem of data volume and managing the problem of the latency of information transfer and service connection is critical to maintaining both the utility and relevance of cloud-based IoT services. These challenges are most acute in the healthcare functioning environments because data processing affects clients' well-being. In this context, IoT has been integrated into healthcare applications as shown in Figure 1, which shows that the IoT can radically change medical services while stressing the importance of efficient data handling and latency minimization techniques.

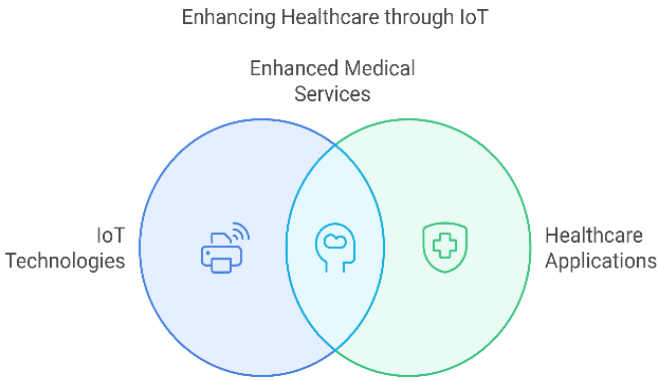

Fig. 1: IoT in Healthcare Applications.

1.1. Importance of Security and Efficiency in IoT Healthcare Applications

In healthcare, technology, especially the IoT, have seamlessly shifted the way care is delivered from one style to another. Security and efficiency are two factors that should not be separated since they are the main priorities that define whether the IoT solutions used in healthcare can be reliable and accepted in various healthcare organizations and by customers [6]. In the healthcare system, it is considered very vital to protect the privacy and security of patients' information. The integration of IoT in operation makes patients release their personal and sensitive health information concerning the disease to the IoT system and the subsequent schedulers presuming that their data will be protected with the highest level of processes. One of how innovation in health care alters security is any security break not only erodes such confidence but also harms the health care provider outcome by dragging the reputation of the health care provider to court with possibly expensive legal implications [7].

Professionals who work in the healthcare industry have the responsibility of protecting patient information by adhering to the legal requirements of data protection as provided by the HIPAA for the US, GDPR for Europe and other countries. They require strict methods for safeguarding health information from invasion, utilization or divulgence to the public. Terms and conditions mandatory with IoT systems guarantee that these legal demands are met so that significant penalties are not incurred [8]. Among the many routine jobs, IoT devices can perform are data entry, monitoring of patients' health, administration of inventory, and many others. Not only does it lighten the

burden placed on healthcare care employees; but also, it eradicates large portions of human input implicating less error and higher efficiency in data recording. This has made it easy for healthcare providers to dedicate most of their time to rendering their services to the patients rather than just signing bureaucratic papers [9].

Besides enhancing business performance, IoT also leads to a reduction of costs in the healthcare sector by enhancing operational performance. Implementing automated systems takes out a lot of the work that can be done manually thus decreasing the labor cost. Furthermore, effective handling of large amounts of data information through IoT can improve the health of a node and give early signals to inefficiency thereby improving health and checking expenses on health complications [10]. Some mHealth applications involved in the delivery of care need real-time data processing that will help them monitor the health of patients. For example, it causes problems in critical care units where the slightest delay in the transmission of data can be fatal. These low latency, high throughput IoT systems ensure that healthcare professionals receive data in real-time and make decisions based on such data in the shortest time possible [11].

Therefore, the reduction of latency in IoT applications boosts not only the development of immediate clinical decisions, but the outcomes of patients too. For instance, notifications received from monitoring appliances can trigger immediate action, which might help avoid medical crises [12]. End-to-end security and reliability are critical to IoT healthcare applications as we shall see later. Safe and effective IoT systems are not only protective of patients' trust as well as meeting all legal requirements but also help improve the quality of healthcare services while decreasing organizational expenses. As technology advances further, these elements in IoT healthcare applications will always be a primary concern of healthcare organizations worldwide [13].

1.2. Objectives of the Survey

The main purpose of this survey is to identify and discuss the main acoustic facets of security and efficiency in IoT in the context of healthcare systems. This survey aims to:

1. Identify and Analyze Security Challenges: Evaluate the threats and risks involved in IoT devices for healthcare delivery. Among the components of risk consideration, it involves the possibility of threats and the outcomes of breaches of privacy and unauthorized access.
2. Evaluate Efficiency Enhancements: This paper examines how various IoT technologies can further the efficiency of operations in a healthcare environment. To do this it is necessary to examine matters such as automation and real-time data processing as well as their implications in terms of healthcare outcomes and efficiencies.
3. Discuss Latency Reduction Techniques: Research and review multiple approaches and tools that enable a decrease of latency in IoT healthcare applications, so vital data can be processed as soon as possible to contribute to patients' treatment and physicians' decisions.
4. Review Regulatory and Compliance Issues: Describe and give detailed information on the implementation of the appropriate use of IoT in the healthcare system and with relation to data protection and privacy laws.
5. Highlight Technological Advancements: Consider the new technologies which aim to solve modern security and efficiency issues and how they may be adopted in the current healthcare systems.
6. Propose Solutions and Recommendations: Proposal and recommendations regarding advice that could be put into practice by the healthcare providers to maintain the security, efficiency and effectiveness of IoT technologies.
7. Assess Future Trends: Anticipate what else might happen to IoT in the healthcare industry in future by drawing from the literature concerning developments that show potential for enhancing the security or efficiency of the entire system.

By so doing the survey will go a long way in promoting the understanding of how IoT can be used to improve the delivery of healthcare with due consideration to the need to afford. scroll Height. This comprehensive exploration will serve as a valuable resource for healthcare professionals, IT specialists, and policymakers involved in the design and implementation of IoT systems in healthcare environments. Figure 2 diagram illustrates the multifaceted challenges affecting the integration of IoT in healthcare.

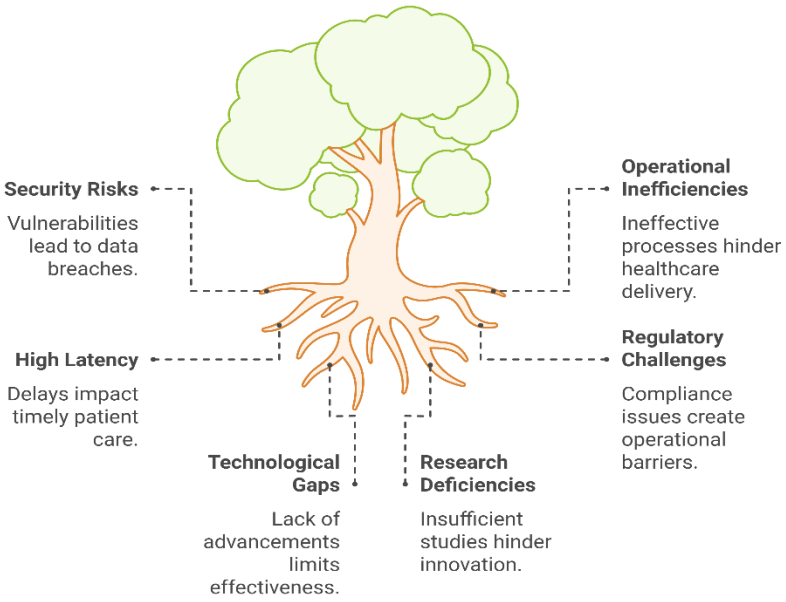

Fig 2: Conceptual Diagram of Challenges in IoT Healthcare Applications

RELATED WORK

Wireless technology in conjunction with sensors has opened up a new frontier in digital health systems, especially in blockchain, boosting the effectiveness of healthcare applications. The concept of the recent study is to introduce more efficient ways of organizing and delivering healthcare services with attended attention on the aspects such as energy consumption, security, and distributed computing.

In [14], a patient healthcare program was proposed to improve energy efficiency and incorporate certifications-based security for protecting remote healthcare services. In a like manner, research [15] and [16] examined power-efficient methodologies for machine learning focusing on supervision learning as a means to address dynamic threats from intrusion. These techniques involved mobile and cloud healthcare applications inside the blockchain network to solve authentication and authorization problems and the problem of inefficient data processing. However, such centralized solutions were found to consume unnecessary resources and increase security risks as compared to managing a large number of, heterogeneous healthcare nodes.

To mitigate all these challenges, Decentralized healthcare systems that integrate both blockchain and IoT were discussed in [17–19]. Such systems employed public Ledger technologies to enhance data-relevant security and optimization of computational energy consumption regarding risks associated with centralized systems. As much as we enjoyed the freedom that blockchain has brought about, its dangers - handling large datasets across nodes - made some challenges emerge in terms of security and energy conservation.

The additional works [20] and [21] built upon the previous research providing solutions that focused on delay improvement and power consumption. New generation fog computing systems integrated dynamic scheduling algorithms and machine learning approaches, which minimized delays in transmitting data between nodules located at fog and cloud layers. However, there remained a crucial problem with delays in model training and testing within blockchain consensus blocks.

The recent developments of federated learning and adaptive scheduling have improved healthcare systems by incorporating smart agreements and machine learning methodology to increase security and energy optimization [22-25]. Such systems were intended to enhance data handling in fog-cloud networks and overcome main problems like latency and power consumption.

New healthcare systems based on blockchain with adaptive and AI elements have been developed to improve security, privacy and energy consumption [26-29]. Such systems apply emerging consensus modalities like PoS and Byzantine Fault Tolerance to anticipate and forestall risks in the IoT networks they manage. Nowadays many

platforms like Ethereum, Fabric, Corda, and others have reached a high level of development, but research focuses on client-side validation and efficient offloading as the key to secure distributed processing. Table 1 provides a comprehensive summary of key studies, detailing the methodologies, security challenges, unresolved issues, and their corresponding outcomes.

Table 1: Detailed analysis of the application, proposed techniques, security problems, and objectives to prioritize.

Ref.	Application	Methodology	Key Security Challenges	Objective	Year
[15]	Managing and Sharing Medical Records	Identification of unknown key exploiters using DLT	Data confidentiality, integrity, availability, and privacy	Develop a secure (DLT) platform for data management	2020
[16]	Remote Patient Monitoring (RPM) and Telemedicine	Bridging blockchain technology and healthcare	Data collection, monitoring, privacy, and security	Ensure safe and reliable RPM using blockchain	2021
[17]	Electronic Health Records (EHR)	Blockchain-based automation for population-level data collection	Data safety, accessibility, and integrity	Enhance EHR security and usability using blockchain	2021
[18]	Data Storage and Security	Coordination of IoT devices through blockchain applications	Authorization, reliability, and secure data transmission	Develop secure methods for data transmission and storage	2022
[19]	Data Analysis and Computation	Integrating blockchain with cloud and edge computing	Safety, dependability, delays, and resource allocation	Optimize decision-making by combining blockchain with edge and cloud processing	2023

IOT-IOMT AND APPLICATIONS IN THE MEDICAL DOMAIN

Figure 3 shows the critical challenges impeding the adoption and use of the Internet of Medical Things (IoMT). To better understand these challenges, numerous research endeavours have attempted to contribute new ideas, all within the IoT scope but particularly in health-related care settings. This section is based on the survey of the recent developments in IoT technologies in the medical domain. The sources cited in this paper are of great quality and have passed through the most popular academic databases such as ACM Digital Library, IEEE Xplore, and Elsevier. The identified studies were screened and selected based on the predetermined inclusion criteria as a mark of relevance, quality, and recency of the studies. This review focuses on the latest research and development in IoT solutions in the healthcare domain such as RPM, tele-consultation, real-time analysing, surgery with robotic assistant and the like.

To achieve the aforementioned objective, the following specific objectives are proposed in this present research: This part also includes the description of such important barriers and the demonstration of potential solutions that can prove that the future of intelligent healthcare and effective patient management is connected through IoMT.

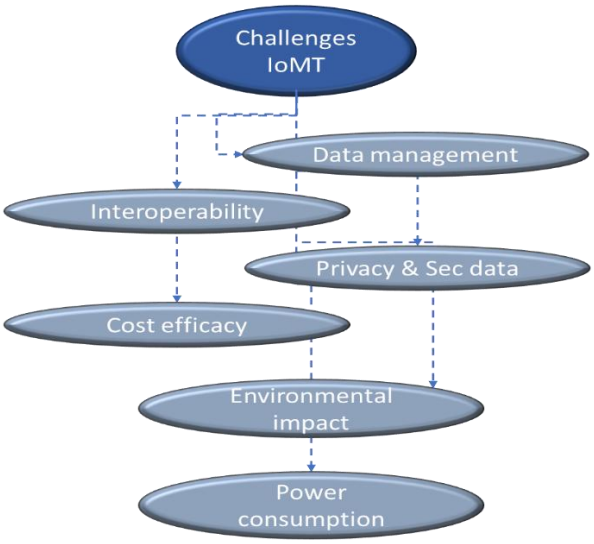

Fig. 3: Challenges in Adopting the Internet of Things.

Applications in healthcare, with an emphasis on the Internet of Medical Things (IoMT), have been the subject of numerous studies, the results of which are summarized in Table 2.

Table 2: Overview of various studies related to IoT-IoMT.

Ref.	Application Description	Solutions and Problems Solved	Algorithms/Methods Used
[27]	Comparing the performance of HTTP and CoAP in healthcare device deployment, including an evaluation of packet volume, loss rate, and data syntax (JSON vs. XML).	**Solutions**: Improved deployment efficiency of healthcare devices in IoT environments. **Problems Solved**: Enhanced QoS and performance through CoAP-HTTP comparisons.	CoAP, HTTP, JSON, XML
[28]	Monitoring patient posture with a custom-designed mattress to reduce storage and computational overhead.	**Solutions**: Accurate patient posture tracking. **Problems Solved**: Improved monitoring precision and minimized storage and computational requirements.	Cohen's Coefficient
[29]	Developing an IoT architecture-based MNS for accurate medication dispensing using various communication technologies.	**Solutions**: Enabled precise medication administration. **Problems Solved**: Enhanced medication dispensing accuracy and efficiency.	Bluetooth, 2G-3G, WSN, RFID, ZigBee, Wi-Fi
[30]	Designing a rehabilitation system using SOA, IoT, optimization, and ontology for diagnostic and resource allocation.	**Solutions**: Improved rehabilitation processes and knowledge-sharing mechanisms. **Problems Solved**: Enhanced efficiency in rehabilitation systems.	SOA, IoT, optimization methods, ontology
[31]	Exploring the integration of m-health, M2M, and 5G technologies to address mobile healthcare challenges.	**Solutions**: Leveraged advanced technologies for better mobile healthcare solutions. **Problems Solved**: Tackled m-health issues with emerging technologies.	M2M, 5G
[32]	Implementing an intelligent system to diagnose Parkinson's disease and assist with patient care in residential settings.	**Solutions**: Supported physicians in treatment, diagnosis, and monitoring. **Problems Solved**: Enhanced care delivery for Parkinson's disease.	Intelligent monitoring, decision support
[33]	Highlighting IoT capabilities for medical care with a focus on 4G health applications and IPV6 connectivity.	**Solutions**: Enabled advanced health applications using IoT and IPV6. **Problems Solved**: Improved potential for 4G medical health services.	IoT, IPV6 connectivity
[34]	Developing a low-cost IoT-based medical device for physiological monitoring with message transmission optimization.	**Solutions**: Cost-effective physiological monitoring system. **Problems Solved**: Efficient message transmission and synchronization.	Message transmission optimization
[35]	Addressing IoT data preservation using semantic and cloud-based approaches.	**Solutions**: Enhanced data preservation and reliability. **Problems Solved**: Tackled IoT data storage and preservation challenges.	Semantic approaches, cloud-based solutions
[36]	Improving patient identification in health monitoring systems with a focus on noise reduction and precision enhancement.	**Solutions**: Accurate and reliable patient identification. **Problems Solved**: Reduced noise and improved precision in patient identification.	Noise reduction techniques, accuracy enhancement methods
[37]	Establishing fundamental IoT-based services and principles in data engineering.	**Solutions**: Provided foundational frameworks for IoT services. **Problems Solved**: Established IoT principles for service development.	IoT principles, data engineering
[38]	Introducing a system for monitoring autistic individuals using personalized sensors for cerebral signal tracking.	**Solutions**: Automated and personalized monitoring system. **Problems Solved**: Enhanced care for individuals with autism.	Automated monitoring, personalized sensors

[39]	Leveraging FPGA technology for CAD algorithm development in kidney ultrasound abnormality detection.	**Solutions**: FPGA-based detection for improved diagnosis. **Problems Solved**: Increased accuracy in identifying kidney abnormalities.	FPGA, CAD algorithm
[40]	Implementing a cloud-based healthcare monitoring system with multiple infrastructure modules.	**Solutions**: Enhanced healthcare monitoring via a modular framework. **Problems Solved**: Improved implementation of medical monitoring systems.	Cloud computing, modular framework
[41]	Developing an Android application for ECG wave monitoring in healthcare using IoT and cloud technologies.	**Solutions**: Seamless ECG monitoring through IoT-cloud integration. **Problems Solved**: Enhanced healthcare app functionality for ECG tracking.	Android app development, IoT integration
[42]	Monitoring patients using health bands to measure heart rates and send alerts based on real-time values.	**Solutions**: Effective health monitoring and communication system. **Problems Solved**: Improved patient care through heart rate-based alerts.	Heart rate measurement, smart health bands
[43]	Designing an IoT-based smart hospital system to improve administration and information management.	**Solutions**: Efficient hospital management system using IoT. **Problems Solved**: Enhanced hospital information flow and system efficiency.	IoT architecture, smart hospital design
[44]	Continuous health monitoring for geriatric patients using an IoT-based system.	**Solutions**: Comprehensive monitoring for elderly care. **Problems Solved**: Improved patient care for geriatric populations.	IoT-based patient monitoring
[45]	Developing a novel methodology for monitoring patients with Obstructive Sleep Apnea (OSA).	**Solutions**: Advanced OSA monitoring techniques. **Problems Solved**: Improved sleep disorder patient care.	Novel monitoring methodology
[46]	Using RFID for developing an IoT-based electronic healthcare model in India, focusing on health data digitization.	**Solutions**: Enhanced healthcare data management through IoT. **Problems Solved**: Digital transformation of healthcare data.	RFID technology, healthcare unit model
[47]	Presenting iCarMa, a methodology for early risk detection in cardiac patients using IoT.	**Solutions**: Early risk identification for cardiac care. **Problems Solved**: Improved monitoring and risk assessment for cardiac patients.	iCarMa methodology

CHALLENGES AND BENEFITS OF IOT IN HEALTHCARE

The Internet of Things (IoT) has been identified as a disruptive technology that brings numerous advantages, significantly enhancing the efficiency of healthcare service delivery, improving the quality of patient care, and advancing medical research [48]. IoT technology allows healthcare practitioners to monitor patients' biometrics and diseases from a distance, supplying real-time data to the system to inform decision-making. This capability not only enhances patient care standards but also reduces the frequency of hospital visits, particularly for patients with chronic diseases [49]. Moreover, IoT helps manage current hospital resources, including beds, equipment, and employees, leading to cost savings and increased quality of service [50].

IoT-generated data through the system is a rich resource for health analyses, as it could help identify patterns and trends, which facilitates efficiency in research in the healthcare sector [51]. It also plays a significant role in the time management of medications, alerting patients when to take their medications, minimizing mistakes, and improving standard medication compliance [5]. Smart IoT devices equipped with sensors can detect emergency circumstances such as falls and send notifications to caregivers or emergency medical services [52]. Furthermore, IoT enhances the feasibility and quality of telemedicine, which in turn offers means for delivering healthcare to areas with limited or no access to either IoT or healthcare facilities, covering the gap left by traditional channels of healthcare delivery [53].

Nevertheless, the integration of IoT in healthcare comes with drawbacks. The issues of security and privacy are particularly concerning, as patient information is often considerably sensitive. Official documents such as medical

records are at risk due to IoT device exposure to cybercriminal attacks [54]. Furthermore, there are concerns about how IoT devices and objects communicate, as they employ a myriad of protocols that prevent easy integration with traditional healthcare architectures [55].

The processing of information in healthcare poses serious problems since the IoT generates vast amounts of data in real time. Each emerging requirement brings another level of challenges and expenses, most especially the regulations like the Health Insurance Portability and Accountability Act (HIPAA) in America [56]. To achieve high levels of user satisfaction, the accuracy and reliability of IoT devices are paramount due to the detrimental impacts of inaccurate measurement results on clinical decisions, which would certainly have repercussions on patients' safety [57].

Another challenging barrier is patient acceptance, especially among elderly patients who may have challenges accepting and using digital health devices. With the issues of patient consent, data ownership, and the possibility of discrimination that may arise from the use of health data, the implementation of IoT faces significant hurdles [58]. These challenges must be solved to optimize the use of IoT in healthcare and to achieve the corresponding advantages. Figures 4 and 5 illustrate the key challenges and benefits of IoT implementation in healthcare, highlighting its transformative potential alongside the obstacles that must be overcome.

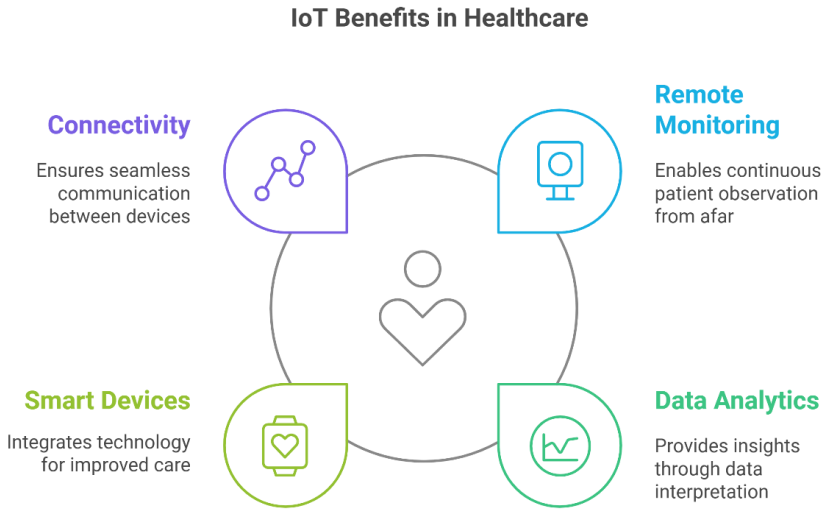

Fig. 4: Benefits of IoT in Healthcare Apps.

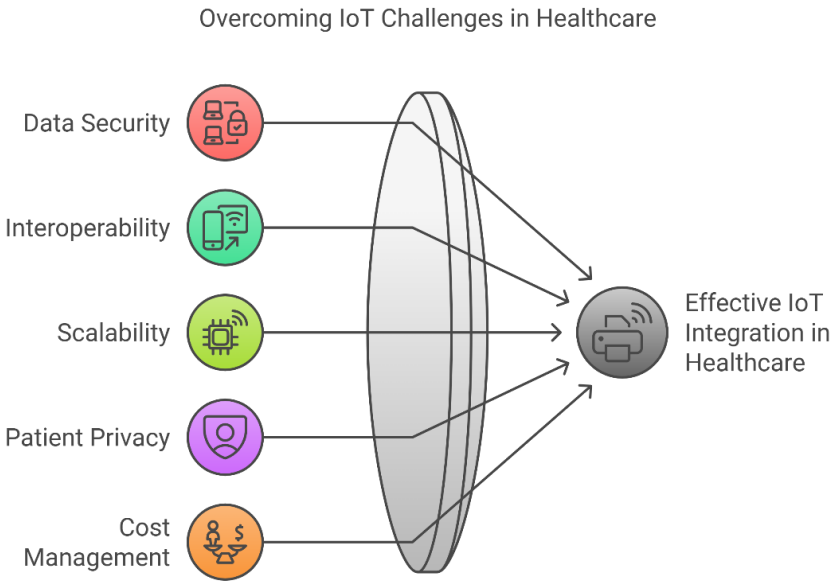

Fig. 5: Challenges of IoT in Healthcare Apps.

SECURITY TECHNOLOGIES AND MEASURES

To protect personal patient data and guarantee the functionality of healthcare services within the framework of the IoT, reliable technologies are required. In this section, the author describes the primary security technologies and approaches that are critical to the secure use of IoT healthcare applications. Encryption is the key enabling technology for IoT healthcare applications and is discussed as the first layer of defence against data threats. Encryption entails the transformation of data sent between devices, or to the cloud, and saved there into a special code, readable only by those possessing decryption capabilities. AES and RSA are two of the most used encryption standards that are used to protect information in rest and motion. The reason lies in the fact that AES is a rather effective working encryption algorithm that is implemented to perform with different key lengths including 128, 192, or 256 to meet the security and, where appropriate, performance requirements of IoT devices [59].

Employed together with encryption, data masking, and tokenization are other measures used to improve the privacy of patient data even further. These methods substitute the actual sensitive data with its non-sensitive equivalent making it possible to use the system safely while denying the actual sensitive data to outsiders. This approach is particularly useful in development as well as testing scenarios where simulation of data exposure poses serious risks [60]. There is a need for encrypted in-house databases that healthcare providers can utilize secure commercial storage solutions for data stored at rest. Currently, these storage systems must implement high-security regulations and laws including the General Data Protection Regulation in Europe, and the Health Insurance Portability & Accountability Act in the US. Preventative and regular audits and checks have to be made [61].

As noted earlier, because of its high strength and persistent efficiency information, AES has been used to encrypt data in almost all IoT health devices. Frequently, keys to Adobe lengths could be modified to develop a unique safety solution that can meet the healthcare gadgets' outlook of security without hindering the efficiency of the IoT devices [62]. RSA algorithm is very useful in cases where particular data have to be transferred through a network and should be encoded. This algorithm is very useful for the establishment of secure communication between two devices if they do not already have secret keys, for encryption with the public key and decryption with a corresponding private key [63].

Figure 6 Comparative Analysis of DES & AES Encryption Processes. The following figures show the steps involved in the DES and AES encryption processes. The first row describes DES operation in terms of 16 rounds, IP, LPT/RPT, and FP. Thus, an à sought cipher text is constructed to be of 64 bits. The next part explains how AES encryption is done. It is shown how to transfer plain text with different key lengths (128, 192, and 256) and incorporate the secret key into the cipher system, as well as generate an encrypted message. The following picture in an attempt to contrast the two encryption methods shows that they have different structures, and the second method is more complex.

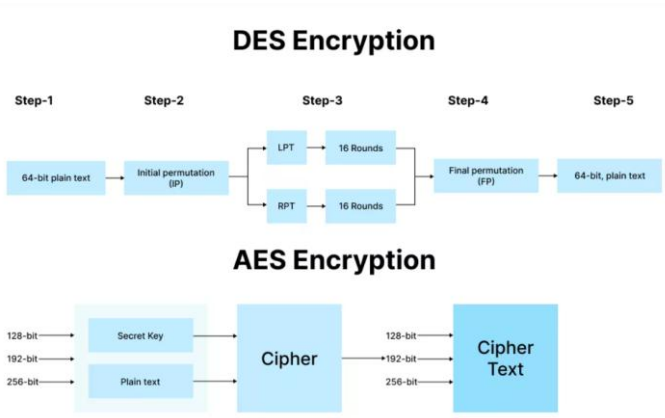

Fig. 6: compares the encryption processes of DES and AES

Multifactor authentication (MFA) is considered to be one of the important security services that boost the security architecture of IoT healthcare systems. MFA involves the use of several factors that a user must produce before he or she can get access to the system or information to be protected. This layered security approach typically involves a combination of credentials from different categories: the input credentials include; something the user knows, for instance, a password, something the user has like a smartphone or a security token and something the user is such

as fingerprints or a facial recognition. This method provides substantial protection from unauthorized access as it is difficult for an attacker to defeat all the varieties of authentication at the same time [64].

RBAC stands for Role-Based Access Control which is one of the best planning methodologies to reduce the accessibility of the system for only those users who have some designated roles in an organization. In particular, RBAC permissions are granted to roles, not to people and that means that the people are only able to use just the data and system functions for performing their tasks. This access control mechanism is important in avoiding the likelihood of either an inadvertent or intentional devastation of sensitive information. It also controls the number of users who may either access or alter private data to improve the entire security of the system [65].

There is an additional layer of security in places where security requirements are exceptionally high, whilst continuous authentication is used. This method implies constant tracking of the user activity in line with the typing rhythm, interaction pace and so on. Through regular verification that the user actively engaged in the system corresponds to the user who was authenticated initially, continuous authentication ensures the security of the system and does not allow others to log into it when the officially authorized person is not present [66].

SHA 256 is used frequently in IoT environments for password hashing mostly because it is secure and very fast. SHA-256 is one of SHA-2 family members which is the cryptographic hash function used to securely apply a change on passwords and derive the unique hash value. It also ensures that our software does not store or transmit actual passwords in their plaintext formats, which would compromise easily identifiable patterns, rendering the application vulnerable to frequently used brute force or dictionary attacks. SHA-256 increases the security consciousness of password management practices since it will be very difficult for a hacker to get a hold of valuable information [67].

The ECC scheme is quite a comprehensive system for digital signatures and key agreement protocols. They adopted elliptic curve cryptography cryptography (ECC)Since it provides nearly the same security as RSA but with smaller key sizes meaning lower computational and power consumption, important characteristics in IoT devices [68].

Collectively, these mechanisms form a robust foundation for securing IoT healthcare systems against various threats and safeguarding patient data and healthcare operations from unauthorized access and breaches. Each method is an important part of the overall security plan that is needed to deal with the unique problems that come up when IoT technologies are used in healthcare settings. Figure 7 shows the SHA-256 hash function process flow, utilized in IoT security to hash passwords and other data. Before entering the padding unit, transaction input flows through an input message interface. Message registers store intermediate states from SHA-256 round operations on the padded message. We merge these rounds' results into the hash registers to get the final hashed output. While, Figure 8 shows public key encryption, which is essential for IoT data security. Before sending data over a secure channel, User A encrypts it with a public key. User B decrypts encrypted data with a private key. In multi-user networks, data security and integrity depend on encryption and decryption.

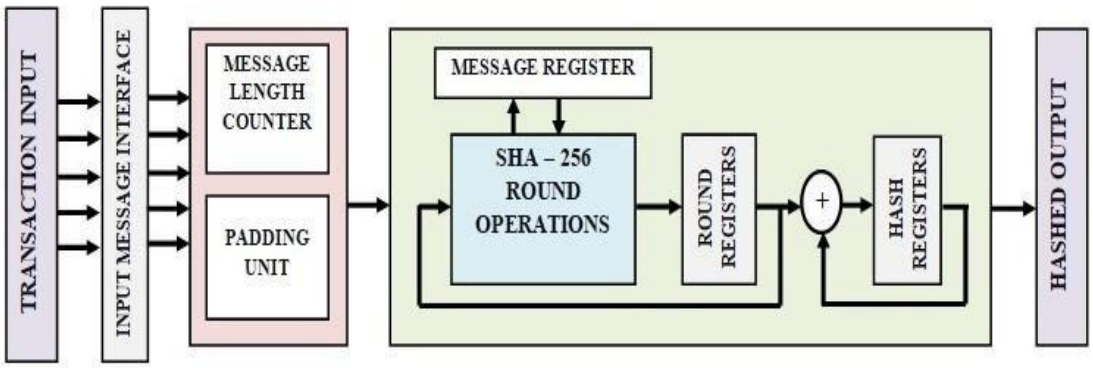

Fig. 7: SHA-256 Hash Function Process.

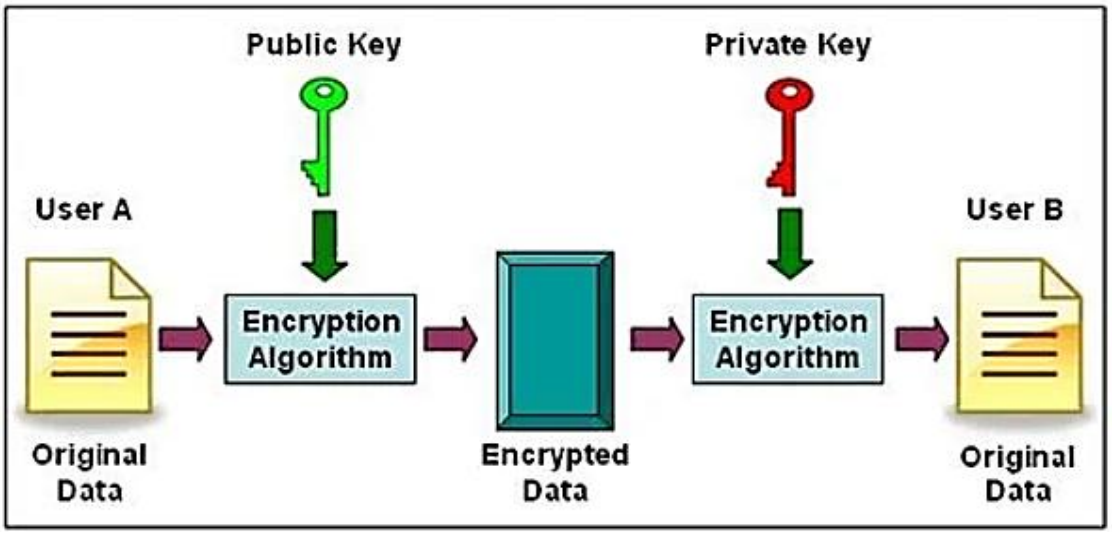

Fig. 8: Public Key Encryption Process.

Transport Layer Security (TLS) and its predecessor, Secure Sockets Layer (SSL), are critical protocols used for securing communications across computer networks. TLS is highly significant to IoT healthcare applications because it provides the security measure needed to cover data transmission between the devices and the servers through encryption. This encryption is crucial in securing some form of health information from unauthorized listening and manipulation so that the privacy and accuracy of the patient data information are preserved during transfer [69].

They are used to establish a private network connection over the internet known as Virtual Private Network (VPN). VPNs help to avoid interception of transmitted data since this tunnel encrypts all the traffic that transmits through it. Such level of security is essential particularly for remote healthcare services and Telemedicine solutions because protecting the privacy and security of health data is highly important. VPNs include encryption, which would protect the privacy of the medical data in case they are transferred using an insecure network from other users [43].

IoT relies mainly on the usage of the Message Queuing Telemetry Transport (MQTT) because of its suitability in managing low-power messages between connected devices. When used with security features, Secure MQTT uses the TLS encryption feature to improve the data security of its transmission. This guarantees the privacy and completeness of all data from which they originated to their destination, a feature critical to the reliability and accuracy of medical data in IoT healthcare applications [71].

Subsequent versions of the TLS, including TLS 1.3, brought additional features which added to the data protection during the transmission even as they continued to provide improvements on the performances that were being offered by earlier versions of the TLS. For instance, TLS 1.3 favours a streamlined procedure of the handshake, which leads to far less time to establish connection security aspects and excludes the employment of outdated and significantly less protect cryptographic choices. Such improvements make TLS 1.3 most appropriate to a healthcare setting since data integrity and use of resources are paramount [72].

This cryptographic algorithm has been found relevant for the safe transfer of cryptographic keys through a public channel and is of paramount importance in establishing encrypted links where no prior secret has been exchanged. Still, the required key exchange is provided by the Diffie-Hellman Key Exchange algorithm which is essential for those cases where IoT devices have to form ad-hoc groups and build secure channels immediately. This algorithm avoids interception of data during initial transfer by establishing a way to create a secret shared key between two parties with no prior knowledge [73].

As depicted in the following figure, the handshake between the client and web server on TLS 1.2 was done. Once the client sends ‘Client Hello’, the server responds with ‘Server Hello’ a certificate, ‘Server Key Exchange’ and finally ‘Server Hello Done’. However, in the second round, the client starts using ‘Client Key Exchange’, ‘Change Cipher Specific’ and ‘Finished’ to ensure that the network connection is secure. The utilization of PKI is shown in Figure 10 to build secure communication. Encrypted messages use public keys taken from key authorities by the senders. When

the server has reduced the ciphertext's encryption, the receiver employs a key to decrypt it to plaintext. This technique just ensures that communication remains personalized and restricted only to the targeted person.

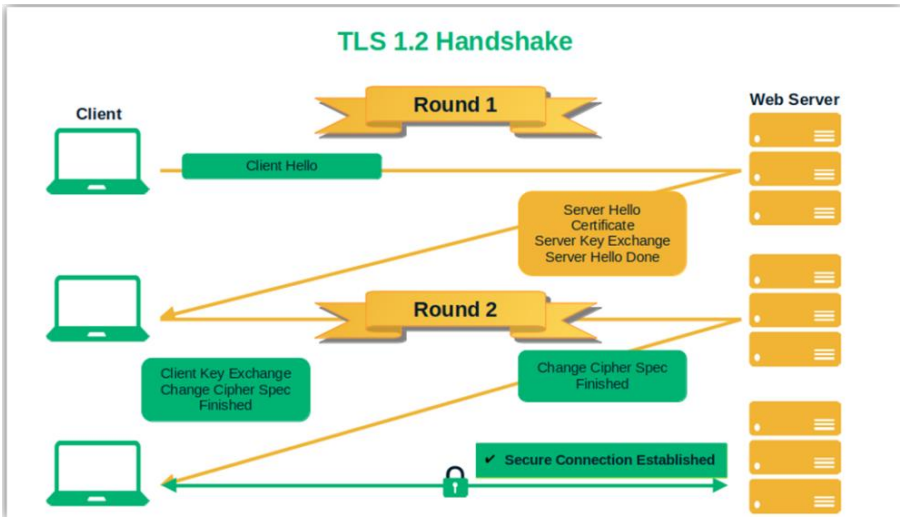

Fig. 9: TLS 1.2 Handshake Process.

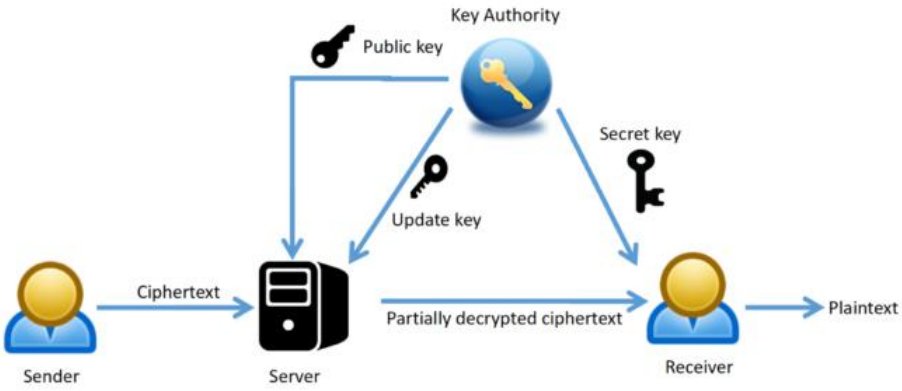

Fig. 10: PKI Communication Process.

DISCUSSION

This section takes an in-depth look at the more complex trade-offs between security, optimization, and performance in applications for IoT in healthcare and finally outlines future trends and likely resolutions in the future of IoT healthcare applications. Incorporation of reliable security measures including enhanced encryption and secure access, brings in certain complexities and may lead to system sluggishness. For example, the procedure of multiple-factor authentication and the concepts of ongoing authentications contribute to security but may cause a deceleration in accessing the systems and decrease user satisfaction [74]. As with encryption routines that ensure data integrity in data transmission, real-time data transfer and retrieval may be slowed down [75].

This is because optimization of security usually comes in contrast with the performance of the IoT healthcare devices. For instance, high security through the use of encryption and real-time malware scanning is desirable but slows down the IoT devices, which are computationally limited in capability and power supply [76].

Improvement of resource use and operating characteristics of systems have to be introduced taking into account performance or efficiency. It is possible to employ specific methods to enhance the performance, for example, data compression and optimized utilization of the protocols but they demonstrate how various aspects can undermine the speed and stochastic stability of the system under certain circumstances [77].

These trade-offs require a careful, activity context-specific approach to the design of health IT security that would most effectively balance security, of course, but also usability/flexibility and performance. Table 3 shows a list of major research papers discussed in this paper concerning trade-offs in IoT healthcare applications.

Table 3: Summary of Studies Analyzing Trade-offs in IoT Healthcare Applications.

Ref.	Year	Focus of Study	Methodology	Key Findings	Trade-offs Discussed
[6]	2021	Security and performance in telemedicine	Experimental simulation	High encryption levels ensure data security but impact device performance	Security vs. Performance
[81]	2020	Efficiency of real-time data handling	Case study	Optimization techniques can enhance efficiency but may affect reliability	Efficiency vs. Reliability
[13]	2022	Multi-factor authentication impact	User study	Enhanced security leads to slower system access	Security vs. User Experience
[8]	2019	Data compression impacts	Quantitative analysis	Data compression speeds up transmission but may lead to data loss	Efficiency vs. Data Integrity
[77]	2021	IoT device battery life	Field testing	Continuous authentication drains battery faster	Security vs. Battery Life
[76]	2020	Real-time malware scanning	Experimental testing	Strong security measures slow down IoT devices	Security vs. Device Performance
[79]	2019	Optimized protocol usage	Simulation study	Protocol optimization improves system response but risks stability	Efficiency vs. System Stability
[75]	2018	Encryption impact on IoT healthcare	Literature review	Strong encryption secures data but increases processing time	Security vs. Processing Time
[12]	2022	Continuous monitoring impacts	Longitudinal study	Continuous monitoring enhances patient care but impacts system performance	Efficiency vs. Performance
[13]	2021	Balancing security and accessibility	Theoretical analysis	High-security levels reduce user accessibility and satisfaction	Security vs. Accessibility

FUTURE DIRECTIONS FOR RESEARCH AND DEVELOPMENT IN IOT HEALTHCARE SECURITY AND EFFICIENCY

Since IoT continues to make its way into the healthcare system, there is always a need to keep on studying as well as innovating to overcome existing challenges and achieve the full potential of the technology. Key domains for future research and development that could substantially improve IoT healthcare security and efficiency include:

1. Enhancing Security through Advanced Technologies: As a result, future studies should focus on improving the lightweight cryptographic methods for IoT concerning data security without hurting the performance of the devices. Blockchain technology has the prospective of offering decentralized security and privacy services and this appears to be useful for protecting IoT care data. This may include retaining clean patient information data and adequately controlling the access logs which are so crucial in maintaining confidentiality. Furthermore, IoT innovation in applying AI security models that anticipate and deter threats is a feature that may improve IoT healthcare security significantly. There is no doubt that a deeper study of the self-learning security systems that can effectively develop their new approaches to counter threats will go a long way in shaping the future of the healthcare security environment.
2. Optimizing Efficiency through Improved Data Management and Energy Utilization: It is high time to enhance the efficiency of data transfer interfaces for low response time and low bandwidth usage, while data security has to remain an important parameter. Burst transmission, which transmits data only at certain vital instances, and other techniques, where data is only transmitted depending on certain algorithms should be further researched. Further consideration must also be given to the energy consumption inherent in the operation of the devices, possible areas for future research extend to technologies for using energy derived from the patient's body heat or kinetic energy. Edge computing is also used to avoid the central cloud and lessen the latencies, and is considered to be a very progressive area for numerous applications that demand immediate reactions or monitoring during emergencies. Creating adaptive solutions that localize data analysis on IoT devices using edge computing will help improve real-time healthcare operational control.
3. Improving Performance with Algorithmic Innovations and Interoperability Standards: On the other hand, the use full real-time data processing algorithm is required in case of remote-control applications

and emergency medical situations. Therefore, prospective studies will require deriving sleek algorithms that can execute optimally on IoT devices with modest power capacity. Interoperability between different IoT devices and systems, as well as the different levels of IoT systems, needs to be achieved as well. The provision of comprehensive standard frameworks and procedures for the integration of interconnective sanitary IoT data transfer will improve both the safety and effectiveness of IoT health care.

4. Regulatory Innovations for Rapid Technology Deployment: As new IoT technologies emerge the creation of flexible legal measures that can effectively address the advancements made in this realm is a prerequisite to their rapid and safe application in the healthcare sector. Further investigation of post-implementation regulatory model flexibility could eliminate most of the bureaucracy healthcare suppliers face and enhance the pace of technology implementation. Also, the continuous automation of compliance mechanisms that guarantee conformity to local laws and international standards would go a long way in improving compliance effectiveness.

Approaching these outlined future research directions with specific focus and development efforts will not only improve the security and efficacy of IoT in the healthcare context and for patients and their operations but also ultimately outcomes. Based on the current development in technology, the three strategies, therefore, require a continuous review of their implementation as a way of fully realizing IoT in healthcare. Such a progressive way of thinking will help the healthcare industry to stimulate growth, improve production rates, and provide services that were impossible in the past.

CONCLUSION

This survey paper aimed to establish a relationship between IoT and its implications for the healthcare sector, from which it emerges how intertwined the two are. In a comprehensive examination of the topic of how IoT advances health care in this paper, various advantages have been distinguished including; Patient telemetry, Health improvement, resource optimization, and big data analysis. Each of these advancements described above has the potential to enhance the delivery of patient experience or create more organisational value. Recent research in IoT shows that it has the potential to address tangible needs in healthcare especially where there is a lack of advanced medicine and personnel for managing/monitoring ailments. Technologies like telemedicine and real-time diagnosis of diseases are revolutionizing care while bringing new problems to IoT-integrated healthcare. Some of the issues noted are similar to many other emerging technologies, for instance, security and privacy, compatibility of the IoT with some other devices, and management of data from the many applications of IoT. Such regulated environments like the HIPAA cause enhancements in the compliance requirements of hardware, software, and services hence complexity and cost. However, reliability is paramount to IoT devices; the wrong information can lead to disastrous consequences in the provision of health care. While conducting the survey, special focus has been paid on between security and performance and between efficiency and performance. These trade-offs make it important to strike the right balance to ensure that the solutions generated through IoT improve rather than complicate the delivery of healthcare services. Some of these challenges may be solved with future trends in IT such as AI and blockchain, utilization of 5G, and edge computing for data protection, less latency, or better integration between systems and infrastructures. Also, this survey described latency minimization and the provisions for the strong safeguards necessary to support real-time applications such as telemedicine, robotic surgery, and emergency response frameworks. Solving these delay problems is important to satisfy the high, low-jitter demands of these applications. Therefore, from this analysis, it is clear that IoT is the disrupting force in the healthcare sector, which has positioned it as a fundamental building block. Yet, the creation of value out of IoT implementations proves not to be easy. Such concerns as privacy of information, compatibility of devices, and compliance with special rules are also to be addressed by stakeholders. Future advancements will require improved security protocols along with refinement in efficiency and reduction in latency levels in the execution of applications in IoT networks. These challenges collectively have presented a new form of opportunity for the healthcare industry to promote more innovative, productive and improved patient care services through the impacts of IoT technologies in enhancing health services delivery.

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