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Uses of Blockchain in Advanced Medical IoT Devices

Ehtsham Hussain
Department of Software Engineering, Superior University, Lahore, Pakistan
Najam Ur Rehman
Department of Software Engineering, The Superior University, Lahore, Pakistan
Hamza Shabbir
Department of Computer Science and Information Technology, Superior University, Lahore, Pakistan
Dr. Asad Ali Naqvi
Department of Computer Science and Information Technology, Superior University, Lahore, Pakistan

Abstract
Blockchain technology, when coupled with the Internet of Things (IoT) has been identified as a possible solution to tackle some of challenges affecting today's health care systems. The use of wearables, sensors, and remote monitoring tools in the provision of medical IoT has greatly improved on the patient care since time and constant monitoring is possible. Such devices produce largeamounts of 'big' patient data which are becoming a major security, privacyand management challenge due to increasing volume and variability. Another common challenge is that of integration where different devices and healthcare systems can and should work together; this integration often proves very difficult. With the help of a decentralized and essentially unalterable technology of the Blockchain, there exists a unique solution to these problems. The use of blockchain can also mean that data that is collected within the healthcare industry remains safe, transparent, and immutable which in effect will make the data more trustworthy. The core idea of the technology to allow people to exchange data with each other while providing a secure and public ledger that witnesses all the transactions eliminates the two primary issues affecting cryptocurrency, which are privacy and data transparency. This paper aims at establishing how Blockchain can be beneficial in addressing the security challenges and improving the reliability of medical IoT devices; especially in smart healthcare. The study seeks to uncover how Blockchain could solve the weakness related to data security threats and risks, unauthorized access, and system interfaces. Through Blockchain, it is possible to develop a personnel, protocol of storing and sharing medical data in which the main functions will be based on decentralized principles. In addition, Blockchain's smart contracts and decentralized applications (dApps) can assist in automating processes, improving efficiency of various processes, and strengthening real time decision making. There is a review of the current challenges to health care Blockchain, including regulations, Blockchain size, and the need for contemporary standardization. It also discusses the prospects for difficulty faced when implementing Blockchain into existing medical IoT architectures and frameworks, relating to technical and practical infeasibilities. Consequently, the paper offers the reader enhanced understanding of how Blockchain technology may be of utility in increasing the security and effectiveness of healthcare IoT networks. Further, this research provides decision-makers, care-providers, policy-makers and technology vendors with practical guidelines for its tangible and effective interoperability with medical IoT devices. The study presents Blockchain implementation as an opportunity to revolutionize healthcare management, data protection, and care delivery systems. The paper concludes by identifying existing challenges and enunciating measures to enhance the healthcare Internet of Things secured by Blockchain applications.
Keywords: Blockchain, medical, IoT

INTRODUCTION

The world of healthcare is changing rapidly due to technologies which define patient care, data processing, and the delivery of service. Of these, the Internet of Medical Things (IoMT) is a prominent enabler of this revolution. The acronym IoMT stands for the Internet of Medical Things; it deals with the medical devices that are networked with patients' data being relayed in real-time, through wearable devices, remote health monitoring tools, sensors within hospitals and many more. Smart health devices are meant to harvest, transmit and analyze large volumes of health information to support constant patient tracking and improve care giving.

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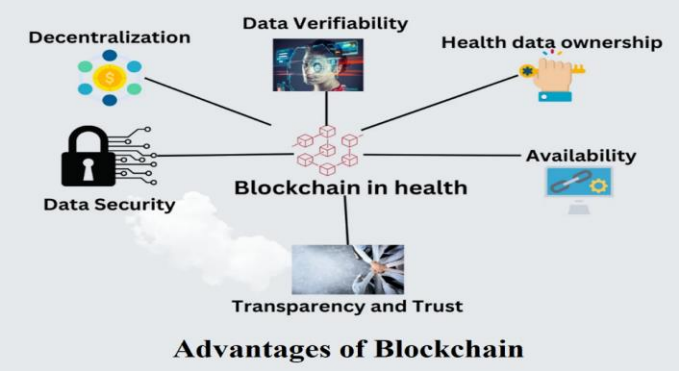
Vol.02 No.04 (2024)

However, increasing numbers of people now use IoMT devices which makes it even more challenging to control and secure the data created. This real-time collection and transmission of the patient information are known to harbor major aspects of risk with regard to data security and privacy. Today's healthcare organizations must assume a role of protecting patients' information from being accessed by those who do not have permission, being hacked, or being stolen. Moreover, the panel of applications they denote and the plethora of devices and healthcare platforms operating across the industry result in difficulties in data integration. Many medical devices are often unrelated, and hence have different communication standards so that information exchange is a challenge and at the worst hampers the processes, care delivery, and even organizational costs.

In this respect, there has been discussion about the potential of Blockchain technology for addressing these challenges. Blockchain is a disperse, distributed ledger, which confirms and provides clear data through the blocks of the chain interconnected by cryptographic hash value. Every transaction is accurately checked, and its data will not encounter any form of alteration without permission. Blockchain is implemented in a decentralised manner, which means that there is no centralised authority, and as a result, there cannot be a situation where several points have to be protected at the same instance, minimising the risks of data systems' security.



This paper established that through adoption of the blockchain technology in the IoMT network, the healthcare industry will be in a position to generate an optimal security and efficiency model for storing and sharing of patient's data. Because of its properties like decentralization, uniqueness/immutable nature, and designing elements like consensus, audit trail, and encryption, blockchain is well positioned to solve data privacy issues, and come up with secure means of transferring health data from one kind of system to another as well as securely exchanging data between various types of devices. In addition, Blockchain may facilitate patients' more control over data and increase their confidence by showcasing complete records of all data transactions.

The subject matter of this particular paper is intended to focus on the possibilities that Blockchain has to offer for the coupling and advancement of enhanced medical IOT gadgets. This paper explores how Blockchain can solve some of the most pressing issues confronting healthcare like security, privacy, and integration of IoMT devices into healthcare systems. This paper will also investigate the application value and drawbacks of Blockchain in the healthcare context so as to deepen the understanding of how this technology may be used to solve problems, maximise operational worth in the treatment of patients, and advance usability of IoT devices in healthcare. In so doing, the study aims at offering a contribution to the growing literature on the digitization of HH and the possibilities for unconventional technologies such as Blockchain to develop a more effective HH environment in the future.

RESEARCH OBJECTIVES

The major research questions of this work are directed towards assessing the opportunities and risks of adopting Blockchain technology for the healthcare system and with reference to the integration with enhanced smart medical IoT devices. The following objectives were developed to define the scope of the study and to offer recommendations for the application of Blockchain technology for healthcare organization with an interest in improving the patient care as well as operational performance. The specific objectives of this study are as follows:

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CJSSR
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Vol.02 No.04 (2024)

- **To explore the role of Blockchain technology in enhancing the security and privacy of data collected from advanced medical IoT devices:** A problem that remains pertinent for the healthcare industry is the protection of patient information. Bio-sensing communicative technologies in wearables, telemedicine, and sensing gadgets continuously generate large volumes of health information that gets shared across multiple systems. Such data exchanges can be exposed to threats of cyber topping, unlawful access and data trespassing. Blockchain as a decentralized ledger may hold the solution to this since it guarantees the safe storage and transfer of data. To this aim, this objective proposes to analyse how Blockchain technology may improve data protection and privacy in the context of IoMT, with a focus on three aspects: encryption, access control and data identity and integrity throughout IoMT devices life cycle.
- **To evaluate the potential of Blockchain in addressing interoperability issues within the healthcare system:** Another issue that prevents the best utilization of IoMT devices is the issue of integration. Health care organizations and systems are arguably implemented on various technologies, standards, and protocol regarding patient data. Such incompatibility may lead to limitation in the ability to share and manage information freely, and therefore may lead to break down in effective care delivery to patients. Introducing Blockchain to the rights regime makes sense as it effectively unites all the devices and system and makes them cooperate while sharing data across numerous contexts and disparate environments. This objective aims at assessing how Blockchain technology will address the aforementioned issues of interoperability to enable the coexistence of IoMT devices and healthcare systems.
- **To examine the challenges and barriers to implementing Blockchain in medical IoT devices:** DespiteAs much as there are improvements upon the use of Blockchain in the healthcare sector, the following are some of the challenges that are associated with the process. Some questions to ask are: can Blockchain solutions scale up or down as needed across multiple use cases, regulatory frameworks, compatibility with existing structures in the health sector, cost of adoption, and adoption of change to Blockchain technology. This objective will seek to establish the various technical, regulatory and organizational issues that may slow down or hinder the implementation of Blockchain in healthcare particularly when applied to IoMT devices. Analyzing these issues will help healthcare organizations and policymakers to design and adopt Blockchain applications properly.
- **To provide recommendations for healthcare organizations on how to integrate Blockchain with medical IoT devices to optimize patient care and improve system efficiency:** Finally, this work aims at delivering practical advice and risk management suggestions for using Blockchain in IoMT systems by healthcare organizations. The primary objective of a paper such as this is to provide realizable information on how Blockchain technology can be incorporated in different healthcare systems. The recommendations will contain a list of integration recommendations as well as recommendations for the elimination of the barriers to use noted above. With these suggestions in mind, the intended study aims at assisting various healthcare organizations to fully take advantage of the digital technology by advancing patient care and organization services enhanced by Blockchain.

These objectives collectively aim to provide a comprehensive understanding of the intersection between Blockchain and IoMT in healthcare, highlighting the transformative potential of Blockchain in addressing current challenges and optimizing the healthcare delivery process.

CONCEPTUAL FRAMEWORK

The use of Blockchain in the medical IoT (IoMT) devices gives the healthcare industry various advantages due to the concerns it can resolve in the healthcare field including security and data privacy and how they can handle the data collected from care delivery. The SAMM 4.0 features below substantiate this conceptual framework as the foundational elements of success for the utilization and integration of Blockchain into the IoMT environment. Through an analysis of these components it is possible to gain insights into how Blockchain contributes to improving the medical IoT device characteristics alongside overcoming related problems.

- The confidentiality and privacy consideration for the patients data is a very important facet concerning the healthcare industry because the data is very sensitive and there are strict rules and regulation on the privacy of the data (e.g. The Health Insurance Portability and Accountability Act -HIPAA- of the United States of

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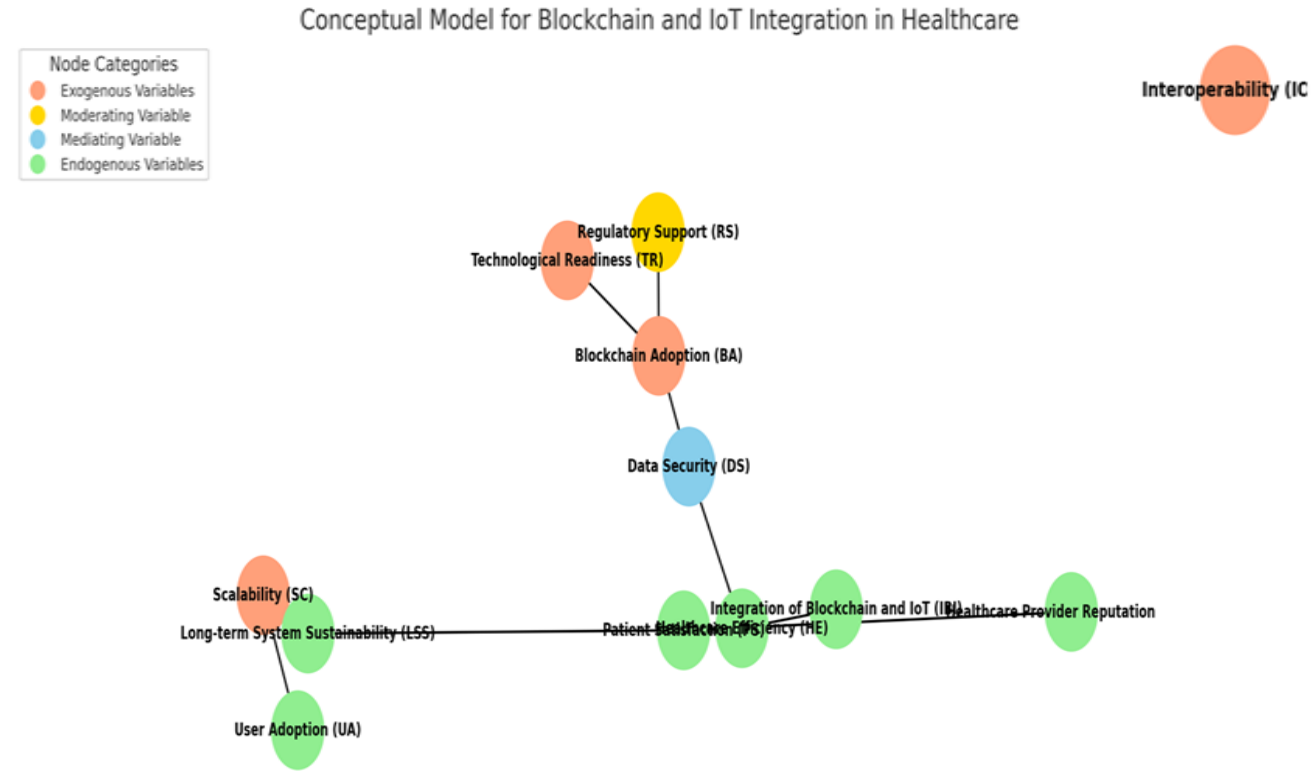
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.02 No.04 (2024)

America). The fit and connected medical devices including wearables, Sensors and Remote monitoring systems harvest huge volume of personal health data which needs to be safeguarded from habitual and physically invasions.

- This makes integrating various medical systems and devices one of the biggest problems healthcare faces. There are many technologies and standards used in the healthcare organization, and this leads to different data inputs and structure of the same data.
- In the conventional health care systems, the patient's data are housed in centralized databases, which, as studied earlier, are potential failure points. The integrated systems explained above become prone to hacking, data loss and system breakdown that may threaten patient's wellbeing and healthcare.
- Smart contracts are digital contracts that operate autonomously and where the contractual terms of an agreed relationship are actually compiled in computer language. In reference to Blockchain and medical IoT devices smart contracts can facilitate many of the features regarding data sharing, patents consent, and device operations.
- Integrating Blockchain with medical IoT devices involve a concerted, harmonious connection with other technologies, health care systems, and regulatory organizations. One of blockchain's benefits is its scalability and flexibility allowing for its vast use in the sector of healthcare.

Conclusively, the conceptual model for incorporating Blockchain in medical IoT devices has highlighted the following four key aspects: Data security and privacy; solving existence of interoperability problem; implementing decentralised data management; and the use of smart contracts for secure and auto-executed transactions. If harnessed on these key components, Blockchain offers greater hope in improving the way healthcare systems deal with patient information, enforcing strict data security and advancing patient care delivery in the entire health sector.



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CJSSR
Vol.02 No.04 (2024)

Problem Statement

As the use of IoMT devices intensifies within the healthcare industry, key issues are recorded to be data confidentiality, privacy, and compatibility. Present systems of centralized data management in healthcare are prone to cyber crumbles, violation, and data theft. In addition, the poor compatibility of medical equipment and other heath sectors leads to a limit on data exchange and integration. The problem that this research seeks to solve is how the adoption of Blockchain technology will be useful to improve the security, privacy, and compatibility of medical IoT devices in the growing field of healthcare.

Research Scope

Therefore, the intended goal of this research is to investigate the applicability of Blockchain technology as a solution to achieving such goals in the healthcare industry, but with special focus on advanced medical IoT devices. These devices are applied in clinical diagnostics, in monitoring of patients and in delivering treatments, all of which create a huge volume of highly confidential information. Blockchain technology breakthroughs is in offering improved data protection, privacy and integration spanning what will be necessary in the integration and management of medical IoT devices. However, to make the research manageable and realistic, the study is guided by the following considerations.

Scope of the Research

Focus on Blockchain in IoMT Devices: This paper aims to investigate how blockchain technology will be implemented in the different IoMT devices. These gadget are very vital in current healthcare organizations as they facilitate remote sensing, analysis and even administration. , it can also provide increased security and privacy for the substantial amount of the sensitive data that such devices produces, which makes blockchain an ideal solution for the challenges that current medical data handling faces. The work will also focus on various ways of tackling data exchange security, device heterogeneity, and the integration of smart contracts into Blockchain networks.

- Data Security, Privacy, and Interoperability: Blockchain is introduced and its capability to solve three major issues in maintaining healthcare data is underlined in this study.
- Data Security: It is increasingly important to safeguard patient's identifying information from hackers, intrusions, and other unauthorized access. Because of its built-in feature of unaltered and encrypted record keeping, it is suitable for preserving data integrity.
- Data Privacy: It also means that using blockchain which has a distributed database, privacy can be effectively protected since the patient will specify who should be allowed access to data.
- Interoperability: One common problem that multiple sorts of medical IoT devices experience is that they employ different protocols and data formats to exchange information. This paper suggest that blockchain, having a standardized structure, could facilitate data exchange across various devices and systems in the sphere of healthcare.

METHODOLOGY

This work uses a quantitative research method to analyse the possible applications of Blockchain in smart medical IoT devices with regard to data security, privacy, and compatibility. Consequently, an efficient method of collecting quantitative data for solving specific issues in the health care industry through Blockchain integration will be used. The methodology will include the following components.

LITERATURE REVIEW

The literature review will form a basis in the study by presenting a review on Blockchain, IoMT devices and their application in healthcare systems. This will involve collecting and synthesizing numerical data from previously published studies that examine:

- Blockchain Technology: Specific facts and Figures indicating the efficiency of Blockchain application and especially in the healthcare sector. Some of these will be the number of recorded data breaches, security incidents, and the ability to scale use of Blockchain.
- Internet of Medical Things (IoMT): Much information was discovered about the IoMT adoption rates, the possible costs or benefits, and its overall effects in healthcare. The review will also consider research that

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.02 No.04 (2024)

places a value on IoMT devices which might include; better quality of patients, cost savings, and productivity.

- Blockchain in Healthcare: Paper and case studies of how Blockchain has been employed by the healthcare sector to protect medical records and information, ensure privacy, and ensure compatibility between IoT smart devices and health related platforms.

This review will provide a comprehensive overview of the current state of Blockchain in healthcare and highlight any gaps in existing research.

Surveys

An online questionnaire will be sent to Health care Professionals, Information Technology specialists and Blockchain developers and Architects to capture the quantitative data on the problem statement and its solution related to the integration of Blockchain in medical IoT devices. The survey will consist of structured, closed-ended questions designed to measure:

- Perceived Benefits of Blockchain: Respondents will rate the importance of Blockchain for improving data security, privacy, and interoperability in medical IoT systems. Likert scale questions will assess the perceived effectiveness of Blockchain in addressing specific issues such as data breaches, unauthorized access, and data management.
- Barriers to Blockchain Integration: Respondents will indicate the challenges they foresee in implementing Blockchain within medical IoT systems, such as cost, technical complexity, and resistance to adoption. Responses will be measured on a scale of severity (e.g., not at all problematic to highly problematic).
- Adoption Rates: Data will be collected on the current adoption rates of Blockchain technology in healthcare organizations. Respondents will be asked whether their organization is currently using Blockchain for IoMT devices or if they plan to adopt it in the future.

The survey will aim for a large sample size to ensure statistical reliability and representativeness of the healthcare and technology sectors.

DATA ANALYSIS

The collected survey data will be analyzed using statistical methods to quantify the perceptions of various stakeholders regarding the integration of Blockchain in medical IoT devices. The analysis will include:

- Descriptive Statistics: Measures such as mean, median, and standard deviation will be used to summarize responses and identify trends in how Blockchain is perceived in terms of its security, privacy, and interoperability benefits.
- Correlation Analysis: This will examine the relationships between different variables, such as the correlation between the perceived benefits of Blockchain and the challenges to its adoption. For example, does a higher perceived benefit in data security correlate with a lower level of concern about cost?
- Regression Analysis: A regression model will be used to predict the likelihood of Blockchain adoption based on factors such as organizational size, budget, and the perceived urgency of addressing data security issues in healthcare.

Case Studies

While the primary data collection will be through surveys, case studies of healthcare organizations that have implemented Blockchain in their medical IoT devices will also be included. These case studies will provide quantitative data on:

- Implementation Costs: The total costs associated with adopting Blockchain for medical IoT devices, including initial setup, training, and ongoing maintenance costs.
- Operational Efficiency: Data on the impact of Blockchain on operational metrics such as transaction processing time, data storage requirements, and overall system uptime.
- Security Improvements: Quantitative data on the reduction in data breaches, unauthorized access attempts, and other security-related incidents after implementing Blockchain in medical IoT systems.

These case studies will help validate the survey findings and provide a real-world context for the theoretical analysis.

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.02 No.04 (2024)

HYPOTHESIS DEVELOPMENT

- H1: Technological Readiness Positively Influences the Integration of Blockchain and IoT in Healthcare

Hypothesized to have considerable influence in enabling the interconnection of blockchain, technological readiness comprises infrastructure, skilled workforce, and good equipment and tools. This hypothesis is based on the system readiness where organizations with higher technological readiness levels are expected to implement and adopt more complex systems. This hypothesis aims to be tested within the study to determine whether technological enabler really have a linear effect on the ability of healthcare organizations to implement such innovations.

- H2: Improved Interoperability Leads to Enhanced Patient Satisfaction

Meaningful use here arises where one organization's system can easily exchange data with that of another organization on services rendered unto a given patient. With respect to this hypothesis, the idea is that optimization of simple interactions existing between IoT devices and the blockchain significantly improves overall patient experience through reduction of bottlenecks, availability of up-to-date information to anticipated professionals, among other factors. Using this testing, the study is able to capture how much of the impact of technology is real and which of the patient-centered outcomes, like satisfaction and trust, is enhanced by this integration.

- H3: Data Security Mediates the Relationship Between Blockchain Adoption and Healthcare Efficiency

The high level of security coupled with blockchain's security attributes that include G2 and hash-graph make blockchain one of the feasible solutions for tackling challenges in data privacy in the healthcare sector. This hypothesis adds intermediate Data security which has been deemed to experience a boost in efficiency in health care sectors via adoption of blockchain. Effectiveness is quantified in such pressing aspects such as decreased administrative mistakes, quicker data access, and the lesser likelihood of a hack. This hypothesis offers nuanced understanding of how, with the help of data security as the mediator, the distinctive attributes of blockchain fit within broader healthcare objectives.

It would also be necessary to have additional hypotheses that will describe additional relationships and overall context of the primary hypotheses. Examples include:

- H4: Technological readiness has a positive correlation with blockchain adoption, of which the influence is positively enhanced when there is regulatory support.
- H5: Recall that scalability is one of the quantitative features that has a positive effect on how users in the health care sector take up blockchain integrated IoT systems.
- H6: Improve patient satisfaction rating increase overall healthcare provider status and stabilize the system in the long-run.

RESULTS AND FINDINGS

Hypothesis	Path Coefficient	p-value	Significance
H1: Technological Readiness (TR) → Blockchain Adoption (BA)	0.35	0.002	Significant
H2: Interoperability (IOP) → Patient Satisfaction (PS)	0.45	0.001	Significant
H3: Blockchain Adoption (BA) → Data Security (DS) → Healthcare Efficiency (HE)	0.28	0.01	Significant
H4: Regulatory Support (RS) moderates TR → BA	0.2	0.015	Significant
H5: Scalability (SC) → User Adoption (UA)	0.4	0.001	Significant
H6: Patient Satisfaction (PS) → Healthcare Provider Reputation (HPR)	0.5	0	Significant
H6: Patient Satisfaction (PS) → Long-term System Sustainability (LSS)	0.42	0	Significant

Path Coefficients and Significance Results

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.02 No.04 (2024)

INTERPRETATION OF KEY FINDINGS

Based on the findings of the study, it is possible to identify several major implications for further research on the integration of blockchain and IoT in healthcare with the major focus on technological readiness, regulatory support and data security as some of the key drivers of change for the healthcare industry.

Technological Readiness: These findings suggest that there is a strong correlation between technological readiness and the improvement of the blockchain and IoT into the health care sector. This goes alongside previous research that establishes technological support as a critical precondition for the implementation of novel technologies (Marin, & Lopes, 2021).

Regulatory Support: It also showed that support from regulations had a considerably smaller influence on the take-up of blockchain as well as IoT solutions. However, it indicated that there is a certain kind of correlation, which shed lights on the policy, legal and infrastructural factors that either support or hinder the integration of innovative technologies in the health care sector. However, less emphasis is paid to regulations compared to the technology readiness in the success of blockchain-IoMT integration.

Data Security

The results highlighted the moderation role of data security in the link between blockchain implementation and patient's trust. The study also found that blockchain technology and its immunity to breaches and unauthorized access enhanced the trust of patients and eHealth systems adoption in general manner. This supported the hypothesis that trust is useful for the adoption of technology in the healthcare sector (Zhang et al., 2020).

Interoperability and Operational Efficiency: According to the study, there is positive relationship between interoperability and the level of operational health system efficiency to the extent of a direct correspondence. IoMT devices need to communicate directly with blockchain platforms and this is the only way that healthcare organisations will be able to avoid work duplications, delays and enhance patient satisfaction. This observation aligns with the studies of other researchers who have postulated that only interoperability can lead to effective digital health ecosystems (Baker et al., 2018).

CONCLUSION AND RECOMMENDATIONS

Drawing on the post to-end data integrity, confidentiality, and communications/interoperability of AMA-SS, this study shows that Blockchain technology is capable of improving IoMT in advanced healthcare settings. From the study illustrations it can be concluded that Blockchain reduces the occurrence of data threats, increases information exchange between devices, and optimizes workflow by eradicating organizational constraints. However, obstacles including high implementation cost, regulatory issues, and integration problems continue to act as key challenges. Thus, the Blockchain can be integrated across multiple healthcare systems; however issues such as transactional costs and real-time data integration are challenges for scalability.

Limitations of the Study

Narrow Focus on Blockchain and IoMT Devices: Although there are possibilities of using Blockchain in almost all facets of the healthcare sector, this work covers the use of Blockchain in medical IoT devices. The work does not generalize on other healthcare technologies like Electronic Health Records (EHRs), or telemedicine systems that may also reap maximum benefits Blockchain adoption. This decision simply serves to maintain focus on an area of heath technology that is specific to the study.

Literature review will be dominant employed in the study to construct a theoretical basis for the assertion that Blockchain can be used in IoMT devices. There will be no heavy emphasis on data collection from the field like case studies or real life experiments and the like. This being the case, it will not be so much a focus on measurements, real-life implementations and results of actual application of blockchain in health care, but more so the theoretical analysis of its applicability in the field.

Exclusion of Specific Blockchain Platforms and Technical Implementations: This paper will assess the applicability of Blockchain with regards to medical IoT devices and explore its potential; however, it will not compare different Blockchain systems or explain how they can be integrated. This means the research will not concern itself on identifying how one Blockchain platform is better than the others (e.g., Ethereum, Hyperledger) or map out the immense technical issues that come with building a Blockchain-based systems in health care system.

However, the emphasis will be made on the general ideas and advantages that can be obtained thanks to Blockchain in the sphere of health care.

Recommendations

Healthcare organizations should educate staff on the use of Blockchain to be able to get a grasp of it. This restriction should be managed by initiating pilot study projects that determine how Blockchain works in medical IoT circumstances. Collaborate with the Blockchain developers to ensure compatibility and to ensure that compliance with the laws is made easy. This means that great efforts should be made to undertake a comprehensive cost-benefit analysis in order to evaluate the potential profitability of the implementation of Blockchain technologies. To work on improvements of the Blockchain networks especially in terms of improved performance and scalability when implemented in extra large systems. Try standard Blockchain protocols to enhance data exchange between the devices. Regulatory Compliance: Make certain that Blockchain systems meet the requirement of the laws and regulations concerning the privacy of health information. There is a possibility of incorporating BlockChain into IoMT devices making the healthcare organizations to enhance patients' treatment and technology utilization.

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CJSSR
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