A SCIENTIFIC AND PRACTICAL ANALYSIS OF RESEARCH ON MANAGING AND MONITORING IOT DEVICES USING BLOCKCHAIN TECHNOLOGY

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Abstract: This research work systematically compiles the most significant scientific studies conducted in recent years on the application of blockchain technology in the management and monitoring of IoT (Internet of Things) devices. The studies are grouped into four main categories-IoT monitoring and service level agreements, analytical reviews, practical prototypes, and domain-specific applications-with each section presenting an in-depth analysis of relevant research. These works explore the architectural, security, efficiency, and functional aspects of the integration between IoT and blockchain technologies, while also highlighting their practical relevance in sectors such as healthcare, smart infrastructure, manufacturing, environmental monitoring, and beyond. The presented scholarly sources offer a solid analytical foundation for ongoing research, practical innovations, and advanced technological solutions in this emerging field

Keywords: Blockchain, Internet of Things (IoT), monitoring, security, analytical research, Edge computing, smart city,

Annotatsiya: ushbu tadqiqot ishi so'nggi yillarda IOT (Internet of Things) qurilmalarini boshqarish va monitoring qilishda blockchain texnologiyasini qo'llash bo'yicha o'tkazilgan eng muhim ilmiy tadqiqotlarni muntazam ravishda to'playdi. Tadqiqotlar to'rtta asosiy toifaga birlashtirilgan-IoT monitoringi va xizmat ko'rsatish darajasidagi kelishuvlar, tahliliy sharhlar, amaliy prototiplar va domenga xos ilovalar-har bir bo'limda tegishli tadqiqotlarni chuqur tahlil qilish. Ushbu ishlar IoT va blockchain texnologiyalari o'rtasidagi integratsiyaning me'moriy, xavfsizlik, samaradorlik va funktsional jihatlarini o'rganadi, shu bilan birga sog'liqni saqlash, aqlli infratuzilma, ishlab chiqarish, atrof-muhit monitoringi va boshqa sohalarda ularning amaliy ahamiyatini ta'kidlaydi. Taqdim etilgan ilmiy manbalar ushbu rivojlanayotgan sohada olib borilayotgan tadqiqotlar, amaliy yangiliklar va ilg'or texnologik echimlar uchun mustahkam

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tahliliy asos yaratadi

Kalit so'zlar: Blockchain, narsalar Interneti (IoT), monitoring, xavfsizlik, tahliliy tadqiqotlar, chekka hisoblash, aqlli shahar,

Аннотация: В данной исследовательской работе систематизированы наиболее значимые научные исследования, проведенные за последние годы по применению технологии блокчейн в управлении и мониторинге устройств IoT (Интернет вещей). Исследования сгруппированы в четыре основные категории - мониторинг Интернета вещей и соглашения об уровне обслуживания, аналитические обзоры, практические прототипы и приложения для конкретной предметной области, - причем в каждом разделе представлен углубленный анализ соответствующих исследований. В этих работах рассматриваются архитектурные, безопасные, эффективные и функциональные аспекты интеграции технологий Интернета вещей и блокчейна, а также подчеркивается их практическая значимость в таких секторах, как здравоохранение, интеллектуальная инфраструктура, производство, мониторинг окружающей среды и за его пределами. Представленные научные источники обеспечивают прочную аналитическую основу для текущих исследований, практических инноваций и передовых технологических решений в этой развивающейся области

Ключевые слова: Блокчейн, Интернет вещей (IoT), мониторинг, безопасность, аналитические исследования, передовые вычисления, умный город

1. Introduction

In the current digital era, the rapid development of Internet of Things (IoT) technologies has led to the interconnection of various devices, enabling the widespread exchange of large volumes of data in real-time. One of the pressing challenges in such networks is ensuring the integrity, reliability, and security of the data. This is where blockchain technology has gained significant attention as a modern and reliable solution. Blockchain allows for the creation of decentralized and immutable databases, enabling full control over data, preventing tampering, ensuring secure data exchange between devices, and providing precise management of access rights. The widespread use of IoT devices in sectors such as healthcare, industry, transportation, energy, and smart cities further enhances the practical significance of blockchain technology. Additionally, blockchain-based approaches are seen as not only timely but also promising, as they address the shortcomings of traditional security systems and enable reliable, transparent information exchange. Therefore, exploring the application of blockchain technology to ensure data integration and security is of significant scientific and practical importance in the development of modern information systems.

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The decree of the President of the Republic of Uzbekistan, PQ–3832, addresses the development of information and communication technologies for the implementation of the "Digital Uzbekistan – 2030" strategy. Although there are no specific directives regarding blockchain technology, the general approaches to ensuring the security of digital systems and services are outlined. The decree also includes initiatives aimed at ensuring the security of electronic services and systems[1].

Furthermore, the President's decree PF-6079 includes strategic directions for integrating data, exchanging electronic documents, ensuring information security, and advancing digital transformation processes, although it does not explicitly mention the use of blockchain technology in public services and other systems[2].

The management and monitoring of IoT devices based on blockchain technology is a highly relevant field in the development of information technologies, addressing issues of IoT system security, efficiency, and reliability. Through this integration, it is possible to achieve decentralized management, ensure the completeness and accuracy of transmitted data, implement real-time monitoring, and utilize automated services.

Research related to the management and monitoring of IoT devices based on blockchain can be classified into the following four groups based on their characteristics.

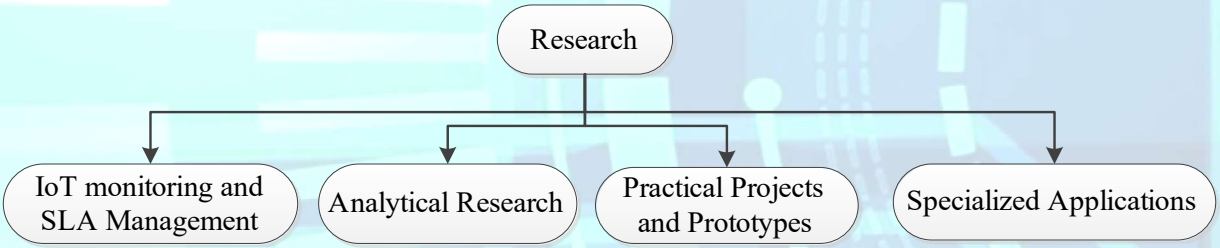


Figure 1. Areas of scientific research

The management and monitoring of IoT devices based on blockchain technology is a crucial area in the development of information technologies, addressing issues related to the security, efficiency, and reliability of IoT systems. Through this integration, it is possible to achieve decentralized management, ensure the completeness and accuracy of transmitted data, implement real-time monitoring, and utilize automated services. In particular, the application of these technologies in strategic sectors such as healthcare, energy, transportation, and industry makes digital ecosystems more sustainable, reliable, and secure. Blockchain enhances control over data in IoT environments through smart contracts, encryption, and transaction tracking, opening up extensive opportunities for both scientific research and practical projects.

2. IoT Monitoring and SLA Management

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In the article titled "IoT Monitoring with Blockchain: Generating Smart Contracts from Service Level Agreements" by Andrew Booth, Abdulrahman Alqahtani, and Eyad Solaiman, the automation of Service Level Agreement (SLA) contracts in IoT monitoring systems is discussed. In traditional systems, SLAs are monitored manually, which can lead to human errors and incorrect oversight. To address this issue, the authors propose converting SLA terms into smart contracts and automating monitoring through a blockchain system. This approach enhances the reliability and transparency of the monitoring process. In the research titled "A Scalable Architecture for Monitoring IoT Devices Using Ethereum and Fog Computing" by Saeid Tahmasebi, Javad Habibi, and Amir Shamsaie, the challenge of dealing with large data streams and the load on centralized servers in IoT device monitoring is raised. To address this, the authors propose an integrated scalable architecture using Ethereum blockchain and fog computing technologies. This approach reduces network latency and improves the overall performance efficiency of the monitoring system[3,4].

The paper "IoT Blockchain Solution for Air Quality Monitoring in Smart Cities" by Sarah Benedict, Paul Rumaise, and Jasleen Kaur emphasizes the need for reliable air quality monitoring in modern city infrastructures. In traditional systems, data may be susceptible to manipulation. Therefore, the authors suggest securing and transparently storing data collected from air quality monitoring devices through blockchain, ensuring reliable information exchange in environmental monitoring. In the research "Low-Cost IoT Air Quality Monitoring Station Using Cloud Platform and Blockchain Technology" by Ahmed K. Hassan, Mostafa S. Saraya, Ahmed M. T. Ali-Eldin, and Mohamed M. Abdelsalam, the issue of high costs in monitoring systems is addressed. This issue is resolved by integrating low-cost IoT devices, cloud platforms, and blockchain technology. The proposed architecture enables the creation of an affordable, energy-efficient, and secure air quality monitoring system[5,6].

Mark Joseph Baucas, S. Andrew Gadsden, and Petros Spachos, in their work titled "IoT-based Smart Home Device Monitor Using Private Blockchain Technology and Localization," focus on ensuring the monitoring and security of smart home devices. The paper raises the issue of trust when devices communicate with each other. The authors develop a precise and secure monitoring system for each device's location and activity using private blockchain networks and localization technologies[7].

The article "Blockchain-enhanced IoT Ecosystem for Healthcare" by Sujata R. Mallick, Sasmita Sobhanayak, and Rabindra K. Lenka analyzes the integration of IoT and blockchain technologies in healthcare systems for monitoring and management capabilities. They identify problems related to the confidentiality and

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integrity of patient data in existing systems. As a solution, the authors propose storing and managing data collected via IoT devices using a blockchain system. In the review "Secure Data Sharing with Blockchain for Remote Health Monitoring Applications" by Venkata Upadrista, Shahid Nazir, and Huaglory Tianfield, the issue of secure data transmission for remote healthcare monitoring is discussed. The authors propose an authenticated and authorized data exchange mechanism based on blockchain, ensuring the continuity and security of healthcare data[8,9].

The article "An Overview of Blockchain and IoT Integration for Secure and Reliable Health Records Monitoring" by Saqib Alam and co-authors discusses the secure monitoring of data from IoT devices in healthcare. The authors propose an architecture that ensures health records are stored in an immutable and verifiable format using blockchain, which enhances the confidentiality and reliability of patient data. The "EdgeChain" framework developed by Jing Pan, Jing Wang, Andrew Hester, Ismail Alqerm, Yuxin Liu, and Yifan Zhao organizes IoT monitoring based on edge computing and blockchain integration. The paper addresses the issues of load on central servers and network latency. The EdgeChain architecture enables local management of devices at the network edge using smart contracts, ensuring fast and efficient monitoring[10,11].

In the paper "A Conceptual Blockchain-Based Framework for Secure Industrial IoT Remote Monitoring" by Mohammad Reza Ghaderi and Amir Eghbali Ghahyazi, a secure remote control system for industrial IoT monitoring is discussed. The paper addresses the issue of data falsification in real-time monitoring. As a solution, a reliable and auditable monitoring system is developed using blockchain technology based on Hyperledger Fabric[12].

These studies explore various possibilities for monitoring IoT devices using blockchain technology. Each paper aims to address issues of security, efficiency, and reliability in IoT systems through unique approaches. Blockchain technology serves as an effective tool for protecting information, ensuring transparency, and reducing errors in these systems. For example, automating monitoring processes by converting Service Level Agreements (SLAs) into smart contracts, ensuring the reliable storage and transmission of data in urban and healthcare systems, and securely conducting remote monitoring in industrial IoT systems are clearly demonstrated through the use of blockchain technology.

Technologies such as Ethereum, Hyperledger Fabric, and edge computing assist in effectively managing large numbers of devices and data streams in IoT monitoring. The articles also explore practical issues such as developing low-cost and energy-efficient solutions for IoT systems, ensuring secure interaction between devices in smart homes, and integrating blockchain for air quality monitoring in urban infrastructure. Additionally, the advantages of blockchain systems for

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protecting and securely transmitting patient data in remote healthcare monitoring are highlighted.

Overall, research on managing and monitoring IoT devices based on blockchain technology offers various solutions aimed at enhancing security, transparency, and system efficiency. This field will continue to develop rapidly, and innovative technologies will further improve the efficiency of IoT monitoring systems.

3. Analytical Research

Analytical research conducted on this topic serves as a crucial foundation for identifying existing achievements and shortcomings in the field, evaluating the advantages and limitations of technological integration, and developing novel solutions. Through such investigations, the practical application of blockchain in IoT systems can be thoroughly examined, including its role in enhancing security, network efficiency, real-time monitoring, and data reliability. Moreover, analytical studies demonstrate how these technologies can be successfully implemented across various sectors-such as healthcare, transportation, energy, smart cities, and industry-thereby enriching theoretical knowledge and contributing to the development of practical roadmaps for implementation.

In the study titled "Integration of Blockchain and Edge Computing in Internet of Things: A Survey", Hassan M. A. and Samad S. investigate the integration of blockchain and edge computing technologies within IoT systems. The authors analyze the role of blockchain in ensuring security and the capacity of edge computing to enhance computational efficiency. This integration is particularly significant in systems requiring large-scale data processing and rapid computation.

Similarly, in "A Survey on the Applications of Blockchains in Security of IoT Systems", Ali M. I. and Shah A. M. focus on the role of blockchain in securing IoT environments. They examine the various threats and vulnerabilities inherent in IoT systems and how blockchain technology can mitigate these risks [13-14].

Khan S. U. and Ahmad K., in their study "Securing IoT Applications using Blockchain: A Survey", explore the potential and challenges of using blockchain to secure IoT applications. The authors discuss the role of blockchain in authentication and data encryption and how it can contribute to the security of IoT systems.

Chakraborty A. and Das S., in "A Survey on the Adoption of Blockchain in IoT: Challenges and Solutions", analyze the obstacles and solutions associated with blockchain adoption in IoT systems. They address issues such as high energy consumption, slow data transmission, and system complexity, proposing innovative technologies and approaches as potential solutions.

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In "A Survey on Emerging Blockchain Technology Platforms for Securing the Internet of Things", Ghosh S. and Tripathi A. examine emerging blockchain platforms for enhancing IoT security. The authors assess platforms like Hyperledger and Ethereum, highlighting their integration potential and benefits in improving IoT system security [15-17].

Zhang W. and Chen J., in their research "Blockchain-enhanced IoT Ecosystem for Healthcare: Transformative Potentials, Applications, Challenges, Solutions, and Future Perspectives", explore the integration of IoT and blockchain in healthcare systems. They analyze blockchain's benefits in applications such as health monitoring and electronic health records and its role in increasing efficiency within healthcare services.

In "Secure Data Sharing with Blockchain for Remote Health Monitoring Applications: A Review", Patel R. and Verma S. examine secure data exchange in remote health monitoring through blockchain technology. They analyze how health data collected via IoT devices can be shared securely, emphasizing blockchain's role in ensuring data privacy [18,19].

Singh S. and Kumar A., in "An Overview of Blockchain and IoT Integration for Secure and Reliable Health Records Monitoring", analyze how blockchain and IoT integration contributes to the secure and reliable monitoring of health records. The authors demonstrate how blockchain protects healthcare records and how IoT devices can be employed for their continuous monitoring.

In "IoT Blockchain Solution for Air Quality Monitoring in Smart Cities", Patel H. and Sharma P. explore the use of blockchain technology in air quality monitoring for smart cities. They highlight the advantages of storing air quality data on the blockchain and conducting real-time monitoring through IoT devices.

Finally, in "Low-Cost IoT Air Quality Monitoring Station Using Cloud Platform and Blockchain Technology", Sharma M. and Gupta R. examine the utilization of blockchain and cloud platforms in developing low-cost air quality monitoring stations. They discuss the transmission of air quality data gathered from IoT devices to the cloud and its secure storage via blockchain, illustrating the effectiveness of low-cost monitoring systems enabled by blockchain [20-22].

The aforementioned studies explore and analyze the application of blockchain technology in IoT systems across various domains. Each work demonstrates blockchain's potential to enhance security, ensure reliable data exchange, and improve system efficiency. The authors elaborate on how blockchain can mitigate risks in IoT systems, protect data privacy, and support the development of real-time monitoring infrastructures.

Additionally, the integration of blockchain and edge computing technologies provides efficient solutions for systems requiring high-volume data processing and

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rapid computation. In the current era, the capabilities of blockchain technology in enhancing IoT system security and facilitating real-time data storage and transmission are of significant importance. Blockchain's role in increasing system efficiency and fostering innovative solutions is becoming increasingly prominent.

In sectors such as healthcare, smart cities, and air quality monitoring, blockchain technology, in conjunction with IoT devices, contributes to the development of secure, efficient, and cost-effective solutions. The studies collectively highlight that blockchain not only plays a crucial role in ensuring security but also in maintaining the integrity and transparency of data. All of these contribute to the advancement of IoT systems and open new pathways for making them even more effective in the future.

4. Practical Projects and Prototypes

Practical projects and prototypes developed within the scope of this field are of significant importance for testing these technologies under real-world conditions, evaluating their operational principles, effectiveness, and security levels. Through such prototypes, the technical and functional aspects of blockchain and IoT integration can be observed in practice, enabling early identification and resolution of potential issues. Additionally, practical projects provide a foundation for assessing how well technological solutions meet user needs in various domains-such as smart homes, healthcare, transportation, and energy-and for improving and commercializing these solutions. This represents a critical step in translating scientific research into practical application.

In the study by Hassan, M. A., and Samad, S., a new framework and prototype titled "EdgeChain: An Edge-IoT Framework and Prototype Based on Blockchain and Smart Contracts" is introduced. This framework simplifies the management of IoT devices by leveraging blockchain and smart contract technologies. The authors analyze the role of blockchain in ensuring security, combined with the rapid processing capabilities of edge computing. The article proposes innovative approaches for the secure and efficient management of data in IoT systems [23].

Ali, M. I., and Shah, A. M. present a scalable architecture in their study titled "A Scalable Architecture for Monitoring IoT Devices Using Ethereum and Fog Computing". This architecture utilizes Ethereum and fog computing technologies to enhance the monitoring of IoT devices. The system increases data transmission speed and ensures low-latency network performance. The article focuses on integrating emerging technologies to improve the efficiency of IoT systems.

In the study by Zhang, W., and Chen, J., titled "IoT Blockchain Solution for Air Quality Monitoring in Smart Cities", the potential of blockchain technology in monitoring air quality for smart cities is explored. The authors demonstrate the advantages of securely and reliably storing air quality data using blockchain and

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tracking this data in real time via IoT devices. The article emphasizes the role of blockchain in improving environmental monitoring in smart city applications [24,25].

Sharma, M., and Gupta, R., in their work "Low-Cost IoT Air Quality Monitoring Station Using Cloud Platform and Blockchain Technology", illustrate how to design a cost-effective air quality monitoring station using blockchain and cloud platforms [26]. This approach lowers the cost of monitoring systems while offering secure data storage solutions. The article aims at developing economically efficient and high-quality monitoring systems.

Patel, H., and Sharma, P., in their study "IoT-based Smart Home Device Monitor Using Private Blockchain Technology and Localization", propose a novel method for monitoring smart home devices using private blockchain and localization technologies. The study explores real-time monitoring of home-installed IoT devices and secure data storage through encryption. The article focuses on improving the security and efficiency of smart home systems.

In the article "Blockchain-enhanced IoT Ecosystem for Healthcare: Transformative Potentials, Applications, Challenges, Solutions, and Future Perspectives", Ghosh, S., and Tripathi, A. analyze the integration of IoT and blockchain technologies in healthcare systems. The authors highlight how blockchain can be utilized in applications such as healthcare monitoring and electronic health records, emphasizing its role in enhancing technological efficiency. The article demonstrates the importance of blockchain for ensuring data security in healthcare systems [27,28].

Patel, R., and Verma, S. explore the benefits of blockchain technology for remote health monitoring applications in their article "Secure Data Sharing with Blockchain for Remote Health Monitoring Applications: A Review" [29]. The authors examine how health data collected via IoT devices can be securely shared and stored. The article illustrates how blockchain ensures data confidentiality and security in healthcare.

In the study titled "An Overview of Blockchain and IoT Integration for Secure and Reliable Health Records Monitoring", Singh, S., and Kumar, A. assess the role of blockchain and IoT integration in the secure and reliable monitoring of health records. The authors emphasize the benefits of real-time health record monitoring through IoT devices and secure data storage via blockchain. This approach contributes to achieving high security in healthcare systems.

Khan, S. U., and Ahmad, K., in their study "A Conceptual Blockchain-Based Framework for Secure Industrial IoT Remote Monitoring", develop a conceptual framework for secure remote monitoring of industrial IoT systems using blockchain. They analyze the use of Hyperledger Fabric to ensure the security of

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industrial systems and enable remote monitoring. The article is aimed at improving the security and efficiency of industrial networks [30,31].

Lastly, in the study by Hassan, M. A., and Samad, S., titled "IoT Monitoring with Blockchain: Generating Smart Contracts from Service Level Agreements", the application of blockchain technology for automating IoT monitoring through the transformation of Service Level Agreements (SLAs) into smart contracts is examined [32]. The study analyzes the automatic management of IoT systems and the enforcement of service contracts via smart contracts. The article offers effective solutions for automated control in IoT environments.

5. Specialized Applications

The specialized domain applications relevant to our research play a significant role in addressing real-world challenges by directing the practical capabilities of technology toward specific fields. For instance, in the healthcare sector, such applications enable secure storage and controlled sharing of patient data exclusively with authorized personnel; in transportation, they support real-time monitoring and optimization of vehicle movements; and in energy systems, they assist in balancing consumption and production. Through these applications, the integration of blockchain and IoT technologies can be tailored to meet the unique requirements, security demands, and functional tasks of each domain. This, in turn, enhances technological efficiency, ensures system reliability, and paves the way for broader implementation.

IoT-based Smart Home Device Monitor Using Private Blockchain Technology and Localization. In this system, smart home devices are monitored using a combination of private blockchain and localization technologies. The primary objective is to enable secure data exchange between devices and facilitate real-time monitoring. Blockchain technology ensures data encryption and secure storage, protecting the system from cyberattacks. Localization technologies provide accurate identification of device locations, offering precise and efficient management solutions.

Blockchain-enabled Smart Home Energy Management. Energy management in smart homes is carried out using IoT and blockchain technologies. This system allows for the monitoring, metering, and management of energy consumption. Blockchain facilitates the tracking of energy sources and enables the automated execution of energy usage agreements, thereby enhancing overall energy efficiency. This technology offers an optimized and more secure approach to managing energy consumption in smart home environments.

Blockchain-enhanced IoT Ecosystem for Healthcare. The integration of IoT and blockchain technologies in healthcare systems is particularly vital for applications such as health monitoring and electronic health record management.

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Blockchain provides secure data storage and access control based on permissions, thereby improving the protection of personal health information. IoT devices allow real-time monitoring of patient conditions, ensuring the accuracy and reliability of health data, and enabling healthcare professionals to deliver timely interventions.

IoT Blockchain Solution for Air Quality Monitoring in Smart Cities. Air quality monitoring in smart cities is facilitated through IoT devices that provide real-time environmental data, while blockchain ensures secure and reliable storage of this information. The system allows continuous tracking of air quality fluctuations and supports informed decision-making to improve environmental conditions. Such solutions play a crucial role in safeguarding public health and enhancing urban sustainability.

Blockchain-based Supply Chain Management Systems. By leveraging IoT and blockchain technologies, supply chains can be efficiently monitored and managed. Blockchain records each stage of the supply chain securely and transparently, increasing trust among all stakeholders. IoT devices enable real-time tracking of goods and materials. This system supports effective supply chain management, provides detailed insights into product movement, and aids in production optimization.

Blockchain-based Vehicle Fleet Management. Vehicle management systems employing IoT and blockchain technologies allow for real-time tracking and recording of vehicle movements and conditions. Blockchain ensures the secure storage of data related to vehicle status, travel history, and operational costs. This system enhances the efficiency of fleet operations and contributes to the reduction of maintenance and operational expenses.

IoT and Blockchain for Renewable Energy Systems. The use of IoT and blockchain technologies in the management of renewable energy resources enables real-time monitoring of energy generation and consumption. Blockchain automates energy transactions and ensures secure execution of contractual agreements. This system improves the efficiency of renewable energy resource management and contributes to the stabilization of energy supply networks.

These research initiatives, combining IoT, blockchain, and other advanced technologies, enable the creation of efficient and secure systems across various domains. The application of blockchain in smart homes, healthcare systems, smart cities, supply chain management, and renewable energy networks contributes significantly to enhancing security and operational efficiency in dynamic environments. Integrated with IoT devices, these technologies ensure transparency, reliability, and data security, while also supporting system optimization and effective resource utilization.

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In each of these systems, the integration of IoT and blockchain enables automated and secure management, as well as real-time monitoring. This is particularly beneficial in smart homes and healthcare systems, where such technologies can significantly enhance quality of life. Furthermore, in smart city infrastructure and renewable energy management, they support environmental improvements and increased energy efficiency.

Overall, these studies demonstrate the future potential of IoT and blockchain technologies to create innovative solutions across numerous fields, particularly in areas such as security, energy efficiency, and resource management.

6. Conclusion

Research findings indicate that blockchain technology plays a critical role in ensuring security and transparency in IoT monitoring systems. Particularly, it has been extensively applied in automating service level agreements (SLAs) through smart contracts, enabling real-time monitoring of device performance, and facilitating reliable data exchange.

Secondly, analytical studies have provided an in-depth examination of the key advantages and challenges associated with the integration of blockchain and IoT. These publications have highlighted issues related to technological compatibility, energy efficiency, scalability, and information security, and have proposed advanced technological solutions to address them.

Thirdly, numerous scientific and engineering projects have developed practical prototypes and system architectures based on blockchain. These efforts have tested innovative approaches to enhancing the monitoring and management efficiency of IoT devices, often integrating platforms such as Ethereum, Hyperledger, and edge or fog computing.

Finally, blockchain technology has demonstrated its potential to enable specialized domain-specific solutions across IoT-driven smart homes, healthcare systems, and industrial environments. Its capabilities are particularly evident in applications such as the secure monitoring of medical records and remote air quality control. As a result, this integrated approach is expected to become an essential component of future digital infrastructures.

The following recommendations are proposed as strategic directions for future research, practical implementation, and technological advancement in blockchain-based IoT device management and monitoring:

Development of scalable and energy-efficient systems: Since many IoT devices operate with limited computational and energy resources, blockchain-based solutions must be designed for high efficiency using lightweight protocols and low-power consumption frameworks.

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Expansion of dynamic monitoring systems based on smart contracts: To enhance automated SLA management, real-time device status monitoring, and rapid emergency detection, further exploration and refinement of smart contract capabilities are necessary.

Strengthening the integration of blockchain with edge and fog computing: In order to reduce latency and bandwidth limitations in IoT systems, integrating blockchain with localized data processing architectures such as edge and fog computing offers a highly effective solution.

Development of domain-specific solutions: There is a pressing need to create blockchain-IoT platforms that are tailored to the specific regulatory and technical requirements of sectors such as healthcare, transportation, industry, and environmental monitoring.

Deepening research on security and privacy: To safeguard the confidentiality and integrity of data transmitted by IoT devices, the use of cryptographic techniques, private blockchains, and isolated networks is recommended.

These strategies aim to ensure that blockchain-IoT integration evolves in a secure, efficient, and context-aware manner, supporting the growing demands of next-generation digital ecosystems..

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