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DrugSure: A Blockchain-Based Framework for Secure Medicine Authentication and Anti-Counterfeit Drug Verification

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Abstract: ***Counterfeit and low-quality drugs are a serious concern for public health, especially in developing and low- to middle-income nations. Lack of transparency, centralized control, and poor traceability systems in the traditional pharmaceutical supply chain create opportunities for counterfeit drugs to enter the market. The existing technology using barcodes and centralized databases has been prone to weaknesses like tampering, duplication, and a lack of public trust. Recently, blockchain technology has received considerable attention as a promising approach for secure drug validation because of its decentralized, immutable, and transparent properties. This survey paper examines and discusses the existing blockchain solutions for medicine authentication and anti-counterfeit drug verification. Different system designs, such as fully on-chain, hybrid on-chain/off-chain, permissioned, and public blockchain designs, have been considered. The paper also points out the important issues of scalability, cost, privacy, and usability, and the research gaps and future work for designing efficient and user-friendly medicine validation systems.***

Keywords: ***Blockchain, Counterfeit Drugs, Medicine Authentication, Pharmaceutical Supply Chain, Traceability, Smart Contracts.***

I. INTRODUCTION

The pharmaceutical supply chain is one of the most important elements of the global healthcare system. It helps ensure that drugs produced by pharmaceutical companies reach patients safely and efficiently. However, the growing trend of the distribution of counterfeit and substandard drugs has become a major global concern, especially in developing nations such as India. The involvement of several middlemen in the distribution of drugs makes the pharmaceutical supply chain complex. The counterfeit drug distribution chain poses serious health risks to patients, such as the failure of treatment, resistance to drugs, and even life-threatening diseases. Apart from health impacts, counterfeit drugs also result in substantial economic losses and undermine public confidence in healthcare systems. The main cause of this challenge is the absence of open, secure, and auditable systems for drug authentication. The conventional drug authentication systems, including barcodes, QR codes, and databases, provide little protection against counterfeiting.

However, these methods have a number of disadvantages, such as control by a central authority, the possibility of manipulating data, code duplication, and the lack of real-time verification for the end consumer. This means that patients and pharmacists cannot verify the authenticity of drugs independently. Recently, the use of blockchain technology has been identified as a promising approach to overcome these issues. The decentralized nature, immutability, and transparency of blockchain technology make it an appropriate solution for securing the pharmaceutical supply chain and enhancing the traceability of medicines. Various research studies have proposed blockchain-based solutions for authenticating and verifying anti-counterfeit drugs. This survey paper discusses and analyzes the existing work on blockchain-based medicine validation systems that have been proposed in recent literature. This paper discusses various architectural designs, their strengths and weaknesses, and challenges associated with them. The aim of this survey paper is to present a clear understanding of the current state of advancements in blockchain-based drug verification systems and to present future research directions for developing scalable, secure, and user-friendly medicine validation systems.

II. BACKGROUND AND BASIC CONCEPTS

To comprehend the difficulties involved in the validation of medicine and the technological solutions adopted to overcome them, it is important to discuss the main issues involved in the pharmaceutical sector and the underlying technologies used in current research.

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A. Counterfeit Medicines

Counterfeit medicines are pharmaceutical products that are intentionally and falsely labeled in regard to their identity, composition, or origin. The World Health Organization (WHO) describes these products as substandard and falsified (SF) medical products. These medicines may contain the wrong ingredients, the wrong dosage, or even no active ingredients. In some instances, they may contain harmful or toxic substances.

The existence of counterfeit medicines is a serious threat to the health of the public. The counterfeit medicines may result in ineffective treatment, the development of drug resistance, prolonged illness, and even death. Apart from the health impacts, counterfeit medicines also result in economic losses to the genuine manufacturers. This is especially the case in developing countries where the monitoring of healthcare systems is limited.

B. Pharmaceutical Supply Chain

The pharmaceutical supply chain is made up of various actors who are involved in the manufacture, distribution, and delivery of drugs. Usually, the pharmaceutical supply chain involves the following actors: manufacturers, wholesalers or distributors, pharmacies or hospitals, and the end-users. Drugs are handled by various middlemen before they reach the end-users.

Although the traditional pharmaceutical supply chain has a structured flow, it lacks transparency and traceability. Data about the movement of drugs is typically maintained in a remote and centralized manner, leading to the creation of data silos. The absence of end-to-end visibility in the supply chain makes it prone to being manipulated and also allows counterfeit drugs to enter the chain, particularly in the distribution and wholesale phases.

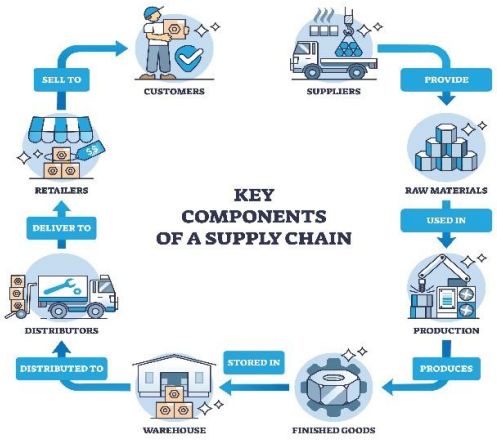


Fig. 1. Traditional Pharmaceutical Supply Chain Architecture

C. Blockchain Technology

Blockchain is a decentralized and distributed ledger system that records transactions on a network of nodes. Data recorded on the blockchain cannot be altered without consensus on the network, making it tamper-proof and secure. There are several features of blockchain technology that are applicable in the pharmaceutical industry, including decentralization, immutability, and transparency. Decentralization eliminates the need for a central authority, thus reducing the chances of data tampering and system crashes. Immutability ensures that any information recorded cannot be altered or deleted, while transparency allows all stakeholders to view a common and consistent version of the transaction history. Such properties make blockchain an ideal technology for improving trust and traceability in medicine validation systems.

D. Smart Contracts

Smart contracts are self-executing contracts that run on blockchain platforms and execute predefined rules and conditions automatically. They do not require any intermediaries and execute actions when certain criteria are met.

In the field of medicine, validation systems make use of smart contracts in order to automate processes such as the registration of medicines, the transfer of ownership, as well as the verification of authenticity.

Smart contracts validate the unique identifiers linked to medicines by making use of the blockchain in order to ensure that the process of verification is secure, reliable, and free from bias.

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III. LITERATURE SURVEY

Fake drugs are a major threat to public health and have a significant impact on the pharmaceutical supply chain. To combat this problem, some researchers have investigated the application of blockchain technology to improve the transparency, traceability, and security of drug distribution systems.

The authors in [1] proposed a blockchain and edge computing solution for securing drug supply chains by using a decentralized method of recording supply chain operations. Their solution enhances the authenticity and verifiability of drugs; however, it is not scalable for large-scale implementation and lacks an analysis of transaction costs.

A hybrid blockchain and IPFS architecture was proposed in [2] to alleviate the storage overhead on the blockchain. In this architecture, only the cryptographic hashes are stored in the blockchain, and the drug information is stored off-chain. Although the proposed architecture alleviates the storage overhead and scalability issues, the privacy issues associated with the access of the off-chain data are not properly addressed, and the latency and throughput performance are not assessed.

The study introduced in [3] is centered on counterfeit drug tracking using a blockchain-based supply chain solution that involves manufacturers, distributors, and retailers. The proposed solution ensures data integrity and traceability; however, the system is not experimentally validated or implemented in real life. The same concept is presented in [4], where blockchain technology is introduced as a remedy for enhancing drug traceability, but scalability and consumer-level verification are not deeply investigated.

In [5], the authors proposed SafeMeds, a blockchain-based medicine verification system that allows medicine verification via QR code scanning. The paper stresses the usability of the system and the involvement of consumers in the verification process of counterfeit medicines. However, important details like scalability, gas usage, and privacy preservation are not explored in detail.

A wider outlook is offered in [6], which offers a systematic review of blockchain applications for supply chain traceability. The authors have pointed out the key challenges, which include scalability issues, high transaction costs, privacy issues, and a lack of interoperability with existing infrastructure. The paper emphasizes the need for lightweight, low-cost, and secure blockchain solutions that are backed by empirical performance analysis.

Finally, [7] presents a thorough literature review of blockchain applications in different areas, including the healthcare sector. The paper categorizes existing solutions and points out the open research challenges, for example, performance optimization, scalability, and security. Although the reviewed solutions are tamper-resistant, most of them do not provide a thorough security analysis and comparison with conventional systems.

From the literature reviewed, it is clear that the application of blockchain technology has been successful in improving the transparency and traceability of pharmaceutical supply chains. However, there are still challenges in scalability, cost optimization, privacy preservation, usability analysis, and real-time performance analysis, which require further research in this area.

In [8], the authors have proposed a blockchain-based drug supply management system integrated with an improved learning scheme to enhance traceability, data integrity, and decision-making efficiency in the drug supply chain. The proposed method has shown improved monitoring of drug movement from manufacturers to end consumers.

The integration of blockchain technology with other emerging technologies such as the Internet of Things (IoT) in the healthcare sector is explored in [9]. This paper points out the importance of blockchain technology in ensuring the security of data sharing and trust among stakeholders in the healthcare sector. It also focuses on its ability to improve drug management and monitoring in the healthcare sector.

In [10], the authors specifically address the traceability of counterfeit medicines using blockchain technology. The system allows for the immutable recording of drug transactions at every stage of the supply chain, thus making it more difficult for counterfeit drugs to be introduced into the market. It is evident from the study that blockchain technology can greatly enhance the security of the supply chain.

Likewise, [11] offers a solution to counter the issue of pharmaceutical counterfeiting by using matrix codes in conjunction with a distributed blockchain architecture. This enables consumers and regulatory bodies to check the authenticity of medicines by scanning codes corresponding to blockchain information.

IV. CHALLENGES AND OPEN ISSUES

Although the use of blockchain technology has the potential to secure pharmaceutical supply chains, there are a number of challenges that make it difficult to adopt on a large scale. On the basis of the survey of the existing literature, the following are the key issues that have been identified.

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A. *Scalability and Throughput*

Public blockchain platforms are known to have low transaction throughputs, thus limiting their capacity to process high volumes of transactions. In the pharmaceutical supply chain, for instance, where millions of units of medicines are produced, distributed, and verified every day, such limitations can lead to high latency and delayed verification. Consequently, fully on-chain blockchain systems are faced with challenges when used in real-time high-volume medicine tracking systems.

B. *High Implementation Costs*

In blockchain-based systems, especially those operating in public networks, there are transaction charges involved in storing the data in the blockchain. These charges are likely to rise when the network is congested. For low-cost and high-volume drugs, especially in developing countries, the total transaction charge may become economically unviable. This is a significant hindrance for small- to medium-scale pharmaceutical companies to implement blockchain-based validation systems.

C. *Data Privacy vs. Transparency*

Although transparency is a crucial aspect in the prevention of counterfeit drugs, over-exposure of data may pose a challenge in terms of privacy and confidentiality. The drug manufacturers and distributors may not be willing to share information regarding their business, such as drug production and distribution, on a public blockchain platform. This is a major challenge in terms of transparency and data privacy.

V. COMPARATIVE ANALYSIS OF EXISTING APPROACHES

This section provides a comparative study of the most commonly used approaches for validating medicines based on certain parameters such as data storage, security, cost, speed, accessibility, and trust model. The comparison is made based on observations that have been reported in existing literature.

Table 1: Comparison of Existing Medicine Validation Approaches

Feature	Centralized Systems (ERP/SQL)	Pure Blockchain Systems	Hybrid Blockchain Systems
Data Storage	Centralized server	Fully on-chain storage	On-chain hash with off-chain storage
Security	Low (single point of failure)	High (immutable ledger)	High (tamper-resistant records)
Cost	Low	High (transaction fees)	Moderate
Speed	High	Low to moderate	Moderate to high
Accessibility	Restricted to authorized staff	Requires blockchain interfaces	Improved consumer accessibility
Trust Model	Trust in central authority	Trust in smart contracts	Trust in smart contracts

VI. RESEARCH GAPS IDENTIFIED

Based on the analysis of existing literature and comparative evaluation of current approaches, several research gaps have been identified in blockchain-based medicine validation systems:

1) Lack of cost-efficient architectures suitable for large-scale deployment
2) Limited focus on consumer-friendly verification mechanisms
3) Insufficient real-time performance evaluation in existing studies
4) Privacy concerns related to public blockchain data exposure
5) Minimal integration with mobile platforms for end-user validation
6) Absence of regulatory and government-level integration

These gaps indicate the need for further research toward scalable, secure, and user-centric medicine authentication solutions.

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VII. CONCEPTUAL SOLUTION MOTIVATION (DRUGSURE)

On the basis of the survey of the existing approaches for the validation of medicines, it is clear that although the use of blockchain technology has improved transparency and traceability, there are limitations in the existing approaches related to scalability, cost of transactions, privacy of data, and consumer accessibility. The lack of trust in centralized approaches, high costs in pure blockchain approaches, and the failure of existing approaches to support real-time consumer-level validation are some of the issues that need to be addressed. To overcome these challenges, there is a need for a hybrid and user-friendly approach to the validation of medicines. This should integrate the security and unchangeability of blockchain technology with efficient off-chain storage solutions, in addition to an intuitive interface for the end-user. The idea of DrugSure is driven by these needs and seeks to investigate a middle-ground solution that utilizes blockchain technology for trust and integrity without sacrificing cost-effectiveness and usability. This conceptual approach emphasizes the importance of future systems that combine decentralized verification with mobile accessibility, allowing consumers to verify the authenticity of medicine on their own while preserving privacy and scalability in the pharmaceutical supply chain.

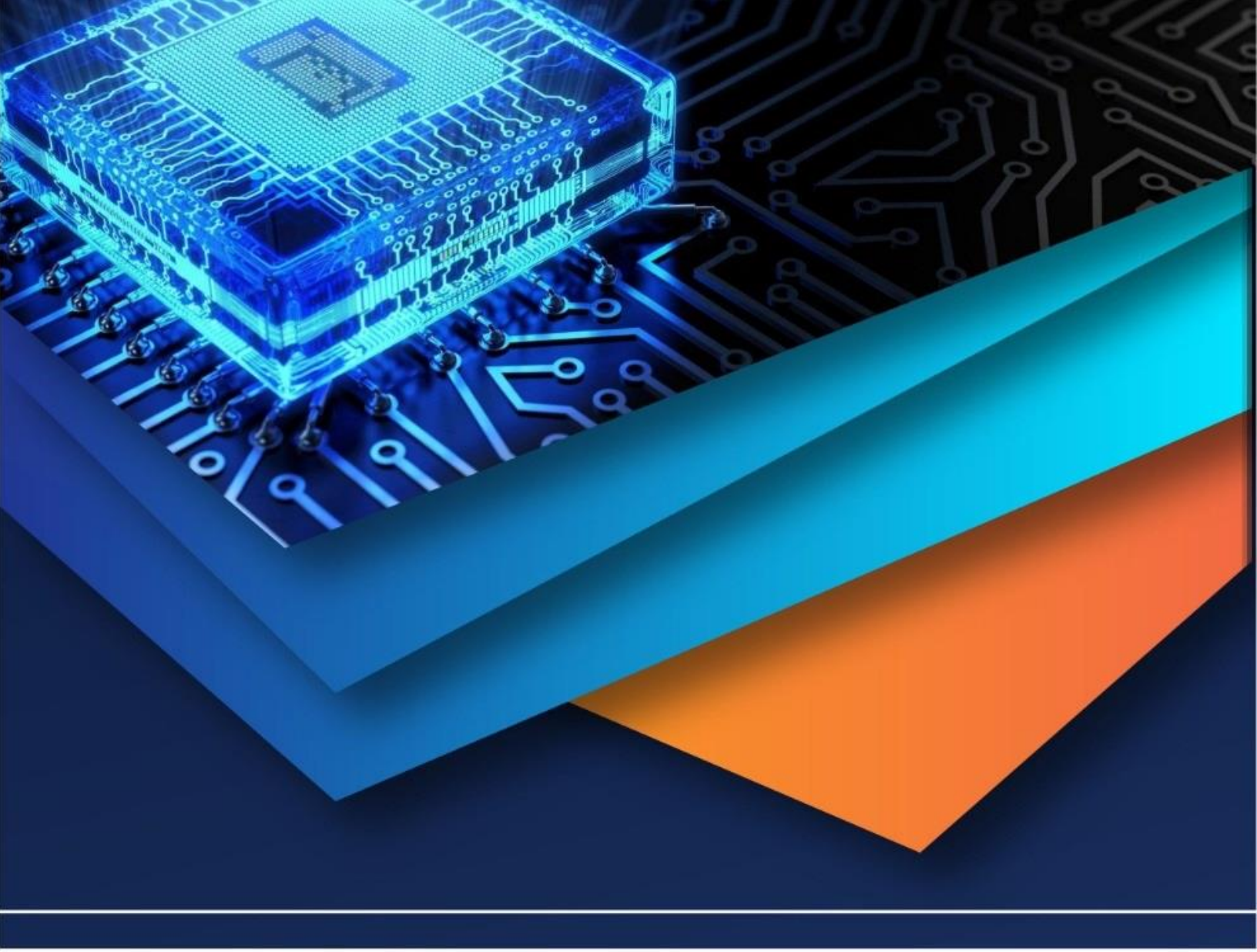
VIII. CONCLUSION

The problem of counterfeit medications has become a global issue that requires sophisticated technological solutions. This paper introduced DrugSure, a blockchain-based framework for validating medications that aims to revitalize trust in the pharmaceutical chain. The proposed solution utilizes a hybrid approach that combines the security of blockchain with the performance benefits of centralized cloud storage. Analysis shows that DrugSure overcomes the high costs and scalability issues of blockchain-based systems by using the Polygon Layer-2 network. This makes DrugSure a cost-effective, user-friendly, and transparent system that allows patients to check the authenticity of their medicines instantly.

Future upgrades will include the integration of IoT sensors for cold chain monitoring (temperature tracking for vaccines) and the use of machine learning algorithms to automatically identify anomalies in the supply chain. These upgrades will work to further enhance the reliability and efficiency of the pharmaceutical verification process.

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