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Systematic Review of Blockchain-enabled eHealth Applications: Metrics and Research Opportunities

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ABSTRACT

The Internet of Things (IoT) has led to the development of various applications, including eHealth applications, which leverage Information and Communications Technology (ICT) to improve healthcare services. However, eHealth applications face various challenges, which the adoption of Blockchain technology can help. In this context, this paper presents a systematic review methodology for analyzing the use of Blockchain technology in eHealth applications. Through this review, the paper aims to identify the key metrics employed in eHealth applications with Blockchain and research opportunities associated with Blockchain technology and eHealth. By mapping out the metrics and opportunities in this area, this paper aims to contribute to developing more effective and efficient eHealth applications.

KEYWORDS

Blockchain, eHealth, Research Opportunities, Systematic Review

1 INTRODUCTION

The Internet of Things (IoT) has many types of applications, one being the eHealth applications [4][8]. The eHealth applications are defined as solutions in the health area using Information and Communications Technology (ICT), according to the World Health Organization (WHO)[9]¹. Besides, eHealth applications can also be defined as a set of computational solutions related to health areas that use the internet to provide better services and conditions to users [14] [7].

The eHealth solutions have many challenges, such as privacy and security access to user data. User data of the eHealth application are considered sensitive because it provides information about the pathologies and treatments of the patients [13] [15]. Most eHealth applications require robust security and data privacy techniques to prevent unwanted user information distribution [6].

Blockchain is known for being the technology that enabled the creation of cryptocurrencies. Blockchain is a technology that supports distributed, reliable, and secure transactions for participants in a large-scale Peer-to-Peer network. It is a disruptive technology,

as the network nodes do not necessarily trust each other, and there are no third parties to mediate transactions carried out between other nodes present in the network, as commonly happens in a financial transaction between two individuals [2].

Figure 1 illustrates a generic Blockchain, where each block contains a set of transactions and a hash to indicate the previous block. This data structure forms the Blockchain. The Blockchain structure is replicated across all nodes in the network. A consensus algorithm decides which node will be responsible for publishing the next block. Consensus algorithms can be Proof of Work (PoW) or Proof of Stake (PoS) [16]. However, it is possible to apply this technology in several other applications to benefit from its security and immutability characteristics [3]. Currently, studies aim to introduce Blockchain technology in applications that require these resources [14].

This study aims to investigate the current state-of-the-art of use Blockchain technology in eHealth applications. It also analyzed the metrics employed in these approaches and the research opportunities in this area. To achieve this goal, a systematic review methodology was employed to identify relevant works focusing on integrating eHealth and Blockchain systems.

This article is divided into the following sections: The systematic review section presents the methodology used to conduct this review. The results section presents the metrics and research opportunities found in the systematic review. The limitations and threats to validity section presents the limitation points of the present work, and, finally, the last section presents the conclusion of the work.

2 SYSTEMATIC REVIEW METHODOLOGY

The systematic review methodology was implemented using a formal process of bibliographic research that aims to present the state-of-the-art relation to eHealth applications and Blockchain.

It adapted a systematic review guide procedure proposed by [12] to this work theme. This modification was proposed by [5], and through this procedure, relevant works were selected that use Blockchain technologies in eHealth applications. Figure 2 illustrates the steps of the methodology used for the review procedure.

¹Available in: <https://www.who.int/>. Accessed on: November 1, 2023.

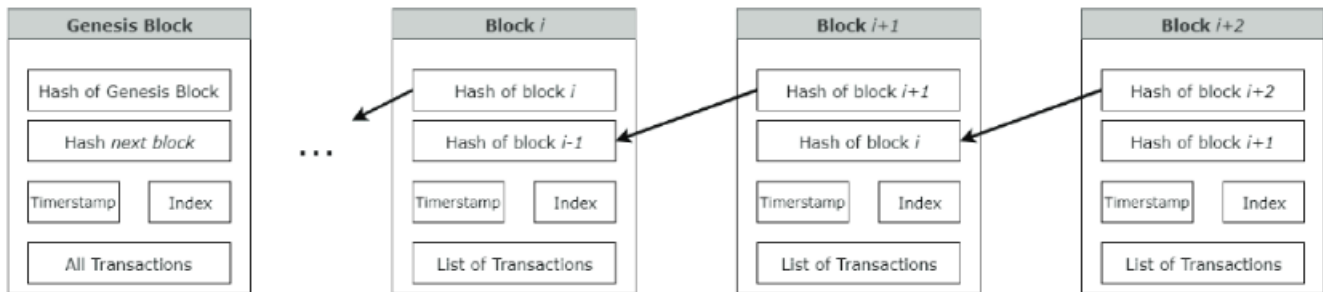


Figure 1: Example of the Blockchain's structure.

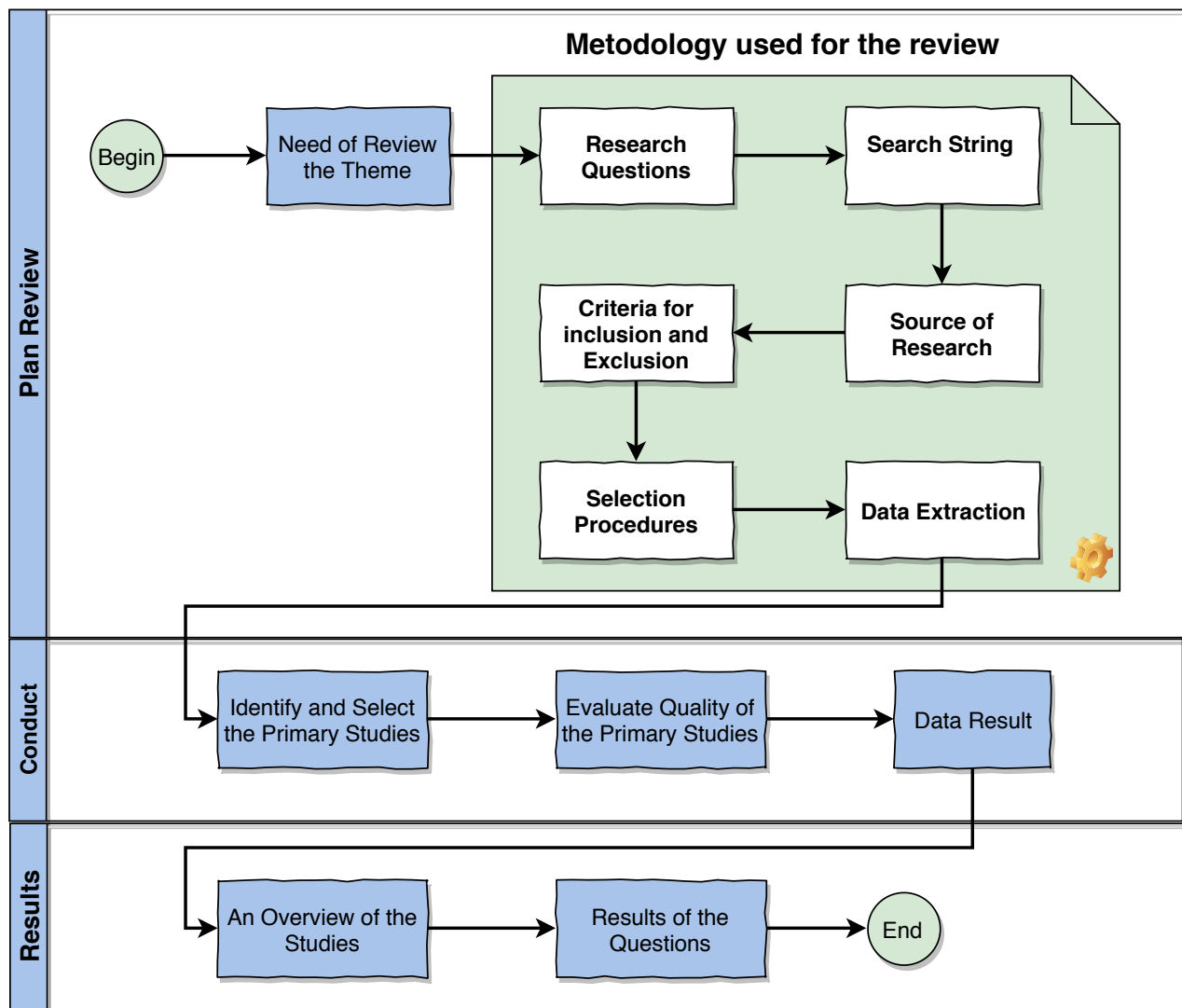


Figure 2: Systematic review procedure.

The procedure is divided into three steps: plan review, conduct, and the results acquired from the previous steps. The plan review defined the research questions, the search string, the research sources,

and the criteria for inclusion or exclusion. The selected papers' data are extracted at the end. Table 1 presents the information of each step in the plan review.

This procedure aims to answer the following research questions: “What are the performance metrics and research opportunities from eHealth systems with blockchain?”.

It was used as a search string for the keywords *eHealth* AND *Blockchain*, and the queries were executed on the following research sources: IEEE Xplore, ACM Digital Library, and Science Direct. The advanced search engine ran the exact search string across all three indexers.

Some restrictions were made to limit the research in the exclusion or inclusion criteria. Only journals and conference articles were included in the search. Another inclusion criterion is articles published between 2015 and 2022. The keywords “e-Health” and “Blockchain” must be included in the articles. These exclusion and inclusion criteria helped ensure that all articles relevant to the research were included.

The work selection process follows the following steps:

- **Step 1:** Apply the search strategy to the search bases;
- **Step 2:** The titles and abstracts of all articles obtained were read and compared with the exclusion and inclusion criteria to select the initial set of studies;
- **Step 3:** The articles identified in step 2 will be read and compared again with the established criteria. The included articles were documented and sent for data extraction.

The conduct presents the execution of the steps mentioned in the plan review. The refinement result selected 15 papers from the IEEE Xplore, ACM Digital Library, and Science Direct search bases. The papers were qualitatively evaluated, verifying the existence or not of the themes “eHealth” and “Blockchain”. The data extraction process was started after defining the set of articles selected for a complete reading. This stage lasted about two months.

Finally, the results were extracted from the 15 papers refined by previous steps. We used JabRef² tool to extract data from the papers collected in the research databases.

3 RESULTS

The results provided relevant data on using Blockchain technology in eHealth applications. It was found two results from this research. The first result maps metrics used in works which presented eHealth applications that used Blockchain. The other is the research opportunities involving the area of eHealth and Blockchain.

3.1 Metrics Mapping

The performance of computational solutions can be evaluated using metrics [5]. Different metrics can be employed to assess the effectiveness of a Blockchain-based solution. The selected works reviewed in this study employed different metrics, some specifically designed to evaluate the Blockchain component, while others evaluated the overall solution.

The used metrics were categorized into two groups: general metrics and specific metrics. A taxonomy was created based on the identified metrics presented in Figure 3. This study aimed to provide insights into the metrics used to evaluate Blockchain-based

eHealth applications and their categorization, which can facilitate the design and evaluation of future systems.

Figure 3 presents the identified metrics and their classification. The figure shows that Blockchain-specific metrics are further classified into two subcategories. Each category of metrics is described in detail below.

3.1.1 General Metrics. The general metrics evaluate the solution’s performance, with or without a Blockchain module. These metrics are commonly used in generic computational applications. However, Blockchain-based applications can also use these metrics. Each general metric is detailed below.

- **Network Throughput**

Throughput is a metric representing the data or packet transfer rate over a network between computing nodes within a specific time frame. It is an essential performance measure for distributed systems, making it a relevant evaluation metric for Blockchain-based systems. The use of throughput as an evaluation metric in Blockchain-based eHealth systems enables the assessment of the system’s efficiency in data transfer and communication between computing nodes.

- **Energy Consumption**

Systems that utilize Blockchain may exhibit high computational and energy consumption, especially when processing large amounts of data. This occurs primarily due to the complexity of the consensus algorithm used to validate a block in the Blockchain. Thus it is crucial to consider these metrics when designing Blockchain-based system.

- **Response Time**

The response time can be defined as the time between the beginning and the end of a determined event in the system. This metric is used to evaluate the performance of the Blockchain system because, depending on the nature of the application, it can affect the system’s quality. The response time in an eHealth application is required. However, this metric could negatively impact the stack of processes for inserting a block and retrieving information from a Blockchain.

3.1.2 Specific Metrics. The specific metrics evaluate the performance only in the Blockchain module. Most Blockchain-specific metrics focus on measuring the time of some Blockchain procedure.

- **Transaction Time**

Transaction time refers to the elapsed time from the transaction’s insertion in a block until the block’s insertion in the Blockchain. This process can be subdivided into two main steps: block creation time and the time to run the consensus algorithm.

- **Block Creation Time**

This metric represents the time the Blockchain waits to send a block for validation through the consensus algorithm. A block can be composed of several transactions that were carried out in a given period.

²JabRef - <https://www.jabref.org/>

Table 1: Plan review information.

Research Question	Search String	Research Base	Criteria of Inclusion
What are the performance metrics and research opportunities from eHealth systems with blockchain?	eHealth AND Blockchain	IEEE Xplore ACM Digital Library Science Direct	Periodicals Conference Papers Period: 2015 - 2022

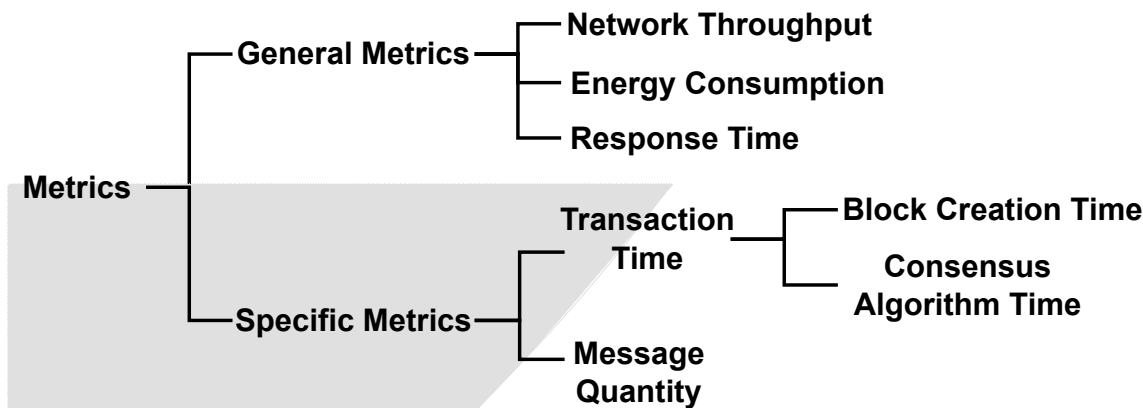


Figure 3: Metrics mapping in e-Health applications with Blockchain.

- **Consensus Algorithm Time**

This metric represents the execution time of the Blockchain consensus algorithm for block validation.

- **Message Quantity**

This metric represents the messages exchanged between the computation node during the Blockchain block creation and validation process.

3.2 Research Opportunities

Research opportunities were extracted from works that proposed solutions and those that listed problems that could be solved with the adoption of Blockchain technology in eHealth applications. The research opportunities found in the systematic review are described below.

- **Electronic Health Record (EHR) Management**

Effective management of Electronic Health Records (EHRs) is a significant challenge in eHealth applications. EHRs contain sensitive patient information, underscoring the importance of safeguarding confidentiality. Consequently, access to EHRs is typically restricted to the hospital institution, and patients can often not directly access their data. This characteristic has significant implications for patient empowerment and poses additional obstacles to the realization of the full potential of eHealth. The use of Blockchain technology presents a promising solution to the issue above. By leveraging Blockchain's decentralized and immutable

nature, healthcare institutions can securely share sensitive patient data. The inherent properties of Blockchain, for example, immutability and transparency, enable a secure and auditable means of transmitting data among institutions while preserving the privacy and confidentiality of patients. Therefore, Blockchain technology can revolutionize the management and sharing of EHRs by enabling seamless, secure, and transparent information exchange between healthcare institutions.

- **Reference Architecture**

The lack of a reference architecture results in the need for interoperability among eHealth systems. Systems are unable to communicate with each other and provide for their users. The analyzed works present solutions with their architectures, making the system's interoperability unfeasible. Adopting a user-centric Blockchain can lessen the impact of the lack of interoperability between systems since the Blockchain will store the data that the user can access.

- **Data Privacy**

Privacy preservation is a significant challenge in eHealth applications, as they entail processing sensitive user data [11]. Blockchain technology has been proposed as a viable solution to address this challenge. Blockchain is a decentralized and immutable distributed ledger that stores data as blocks, each with a unique timestamp [10]. The use of Blockchain

technology offers an innovative approach to securely storing and sharing sensitive medical data while preserving patient privacy [1]. Blockchain's inherent properties, such as immutability, transparency, and tamper-proof nature, provide a robust mechanism for ensuring data integrity and confidentiality in eHealth applications.

• Data Security

Data security is related to the actions taken to preserve the information that users share with the system. The data handled by e-Health applications is sensitive, which requires some security mechanisms for the data handled [18]. Blockchain uses several computational nodes to store blocks; that is, a new block is only accepted when all network members allow it. Another feature is that transactions are carried out encrypted, which increases data security.

• Access Control

Access control plays a fundamental role in eHealth applications. The growing number of eHealth applications provides challenges in managing patient data, such as EHR [18]. This data needs to be available only to healthcare professionals. Blockchain guarantees data protection and integrity. Therefore, Blockchain must be designed to prevent unauthorized granular access to data [17] [18].

4 LIMITATIONS AND VALIDITY THREATS

One limitation of this work is the sample size of the papers selected in the systematic review. This limitation can cause a generalization of the results of the metrics extracted from the papers. The sample size of the papers also can affect the amount of research opportunities found.

5 CONCLUSIONS

In our study, we employed a systematic review approach based on the protocol outlined in [12] to investigate the state-of-the-art eHealth applications incorporating Blockchain technology. The results of this review revealed that the metrics used to evaluate these applications could be categorized into two groups: general metrics and specific metrics. General metrics are applied to assess the system's overall performance, whereas specific metrics focus exclusively on the Blockchain module. Additionally, the review identified and described various research opportunities in this field. The findings of this study provide insights into the current state of eHealth applications that utilize Blockchain technology and highlight areas for further investigation and development.

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