Exploring Blockchain-Based Solutions for Secure Multi-Party Data Sharing in Emergency Management

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ARTICLE INFO

Article History:

Received November 15, 2024

Revised November 30, 2024

Accepted December 12, 2024

Available online December 25, 2024

Keywords:

dual-branch conformer

codec optimization

dual-branch conformer

Speech compression

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ABSTRACT

This study looks into the role blockchain technology can play in improving the safe sharing of data between various parties in emergency management. It seeks to explore how blockchain, coupled with attribute-based access control, can address the issues in centralized data platforms and transform the nature of decentralized data governance. The five core research questions focus on improving data security and privacy, the role of ABAC in dynamic policy adaptation, data sharing efficiencies and reliability, minimizing risks of single-point failures and unauthorized access, and the feasibility of using Hyperledger Fabric for real-world applications. By applying a quantitative research approach, the study assesses how blockchain and ABAC can influence data security, policy adaptation, and system reliability in emergency management. The results are confirmed in terms of significant improvements in data security due to blockchain; the ease of dynamic policy adaptation; better efficiency in sharing data; risk mitigation; and validation of the feasibility of using Hyperledger Fabric for applications in emergency management. This research contributes to the understanding of decentralized data governance and underscores the importance of blockchain in enhancing emergency response systems.

1. Introduction

This chapter discusses challenges in secure data sharing among multiple parties collaborating in emergency management, such as the shortfalls of the traditional centralized data platform and how blockchain technology can revolutionize decentralized data governance. The central research question will be to find out the applicability of blockchain technology for dynamic access control in emergency management. Five sub-research questions will further guide the research: How does blockchain improve data security and privacy in emergency management? What role does attribute-based access control play in dynamic policy adaptation? In what way do the data sharing efficiencies and reliability get improved through this proposed system? Which mechanism minimizes risks of single-point failures and unauthorized access? How practical is this Hyperledger Fabric framework for use in the real world? The study employs a quantitative approach, with the independent variables being blockchain implementation and attribute-based access control, while the dependent variables include data security, policy adaptation, and system reliability. The paper follows the progression from literature review to methodology, presentation of findings, and discussion on implications. This systematically analyses how blockchain technology facilitates secure data sharing and highlights its importance in emergency management.

2. Literature Review

This section critically reviews existing research on decentralized data governance using blockchain in emergency management. The review is structured around the study's sub-questions: enhancing data security, role of attribute-based access control, improving data sharing efficiency, mitigating risks, and viability of Hyperledger Fabric. These areas lead to specific findings: "Data Security Enhancements through Blockchain," "Dynamic Policy Adaptation via Attribute-Based Access Control," "Efficiency Gains in Data Sharing," "Risk Mitigation in Decentralized Systems," and "Viability of Hyperledger Fabric in Emergency Management." Though progress has been made, there are still gaps in research, including a lack of real-world testing, insufficient analysis of policy adaptation dynamics, and challenges in scaling blockchain solutions. Each section advances a hypothesis based on the relations of variables, hence developing a more subtle view about how blockchain can be utilized in emergency management.

2.1 Improvement in Data Security through Blockchain

Initial works focused on the enhancement of security in data sharing via blockchain, highlighting the latter's immutable ledger and decentralization. These studies achieved improved security but mostly lack practical application in environments as high-stakes as in emergency management. Subsequent research extended the test for blockchain in more dynamic scenarios, with some success but still not enough to provide all-around security assurance. Recent efforts bridge these gaps, but challenges are still present to fully unlock the potential of blockchain capabilities for secure data sharing. Hypothesis 1: Blockchain implementation significantly improves data security and privacy for emergency management, as proposed by a tamper-proof and decentralized data governance model.

2.2 Dynamic Policy Adaptation via Attribute-Based Access Control

Early work on ABAC revealed its potential in dynamic policy management but lacked interaction with decentralized systems. The most recent studies attempted to combine blockchain and ABAC and found it potentially adaptive to real-time changes of policy. However, those studies were still in need of testing such adaptations within emergency management scenarios. Hypothesis 2: The integration of attribute-based access control with blockchain technology enables dynamic adaptation of access control policies in response to changing emergency scenarios is proposed.

2.3 Efficiency Gains in Data Sharing

Initial investigations into blockchain's impact on data sharing efficiency focused on its decentralized nature reducing bottlenecks, yet these studies often lacked empirical evidence in emergency settings. Mid-term research focused on the ability of blockchain to facilitate efficient data exchange, showing improvements in efficiency but still struggling with scalability. Recent studies are trying to overcome these limitations, but there is a lack of comprehensive evaluations in real-world emergency management. Hypothesis 3: Blockchain-based systems improve the efficiency and reliability of data sharing in emergency management by reducing bottlenecks and enabling seamless information flow is proposed.

2.4 Risk Mitigation in Decentralized Systems

Early literature reviewed the risk mitigation capability of blockchain such as single-point failures and unauthorized access, mostly in abstract models without practical validation. At this stage, research began to focus on integrating blockchain into emergency management with some success, yet with a lack of solid long-term evaluations. In recent times, researchers have focused on providing empirical validation, yet the knowledge on risk mitigation mechanisms remains incomplete. Hypothesis 4: The blockchain technology does mitigate effectively the threats from single point failures and unauthorized access in a multi-party emergency management scenario, it has been suggested.

2.5 Feasibility of Hyperledger Fabric in Emergency Management

Some of the early research conducted on Hyperledger Fabric concerned its possibilities in decentralized applications, particularly in controlled environment settings. Since then, mid-term studies have pushed the capability further in challenging scenarios where scalability and integrative aspects of Hyperledger fabric were at the forefront and limited this aspect. Current research addresses some of these limitations; however, real-world evaluations are still required. Hypothesis 5: Hyperledger Fabric offers a valid framework for implementing real-world emergency management applications that guarantee the secure and scalable sharing of data is proposed.

3. Method

This section describes the quantitative research methodology used to test the hypothesized hypotheses. It involves data collection, variable selection, and statistical analysis methods that would ensure robust findings on blockchain's impact on emergency management data sharing.

3.1 Data

Data was collected from a series of evaluations on a Hyperledger Fabric-based data sharing system designed for emergency management. Primary sources include system performance logs, access control policy adaptation records, and feedback from stakeholders, which are obtained from emergency management professionals. The data collection period ranges from 2020 to 2023, where random sampling ensures a broad representation of diversity in the emergency scenarios considered. Screening criteria for sample selection will be systems with at least six months' operational duration, covering scenarios of emergencies such as natural disasters and public health crises. This will ensure that the dataset is holistic and capable of evaluating blockchain's impact on data security, policy adaptation, and system reliability in emergency management.

3.2 Variables

Independent variables are the implementation of blockchain technology and attribute-based access control. Dependent variables focus on data security (measured by breach incidents and unauthorized access attempts), policy adaptation (evaluated through policy change frequencies and response times), and system reliability (assessed by data sharing speeds and system uptime). Control variables: The complexity of emergency scenarios and the number of participating entities. These will be critical for isolating the effects of blockchain and ABAC from other influences that may shape broader operations. Literature in both cybersecurity and emergency management validates measurement methods for these variables. The study applies regression analysis to explore relationships and test hypotheses.

3 Results

The results section presents findings from analyses conducted on data from 2020 to 2023, focusing on blockchain's impact on emergency management data sharing. Descriptive statistics establish baseline distributions for independent variables (blockchain and ABAC implementation), dependent variables (data security, policy adaptation, system reliability), and control variables (emergency complexity, participant numbers). These analyses show valid enhancements in data security, policy adaptation, and system reliability through blockchain and ABAC. Hypothesis 1 confirms that blockchain enhances the aspect of data security because breach incidents and unauthorized access attempts were reduced. Hypothesis 2 points out that dynamic policy adaptation is a feature enabled by the introduction of ABAC, demonstrated by higher frequencies of changes in policies and faster times to respond. Hypothesis 3 shows higher efficiency and reliability in sharing data, faster sharing speed, and higher system uptime. Hypothesis 4 stresses that the blockchain system can effectively eliminate the risk of single-point failures and unauthorized access. Hypothesis 5 confirms the applicability of Hyperledger Fabric as a framework for real-world emergency management applications. By relating the findings to the data and variables outlined in the Method section, results illustrate how blockchain technology drives secure and efficient data sharing in emergency management, addressing gaps in existing literature.

4.1 Blockchain's Enhancement of Data Security

This finding confirms Hypothesis 1, indicating that blockchain implementation significantly enhances data security in emergency management. Based on data from the system performance logs and breach records from 2020 to 2023, projects using blockchain report significantly fewer attempts at unauthorized access and breach incidents. Independent variables are key features of blockchain such as immutability and decentralization, while dependent variables will focus on security metrics, such as breach frequency and access control violations. It is inferred that the decentralized architecture of blockchain ensures better security by not allowing alterations in data and maintains system integrity. Empirical significance falls in line with theories related to decentralized security models, as it supports the role of blockchain in enhancing data protection. This finding addresses previous gaps regarding the linkage of blockchain features to security outcomes. The importance of decentralized solutions in safeguarding critical data for emergency management is hereby highlighted.

4.2 Dynamic Policy Adaptation through ABAC Integration

This finding supports Hypothesis 2 as integrating attribute-based access control with blockchain enables dynamic policy adaptation in emergency management. Access control policy records between 2020 and 2023 reveal increased frequencies of policy changes and faster response times in systems using ABAC. The main independent variables are the flexible policy frameworks of ABAC, and dependent variables revolve around adaptation metrics like policy change rates and adaptation speed. The correlation means that ABAC provides the agility required to adjust access controls dynamically as emergency scenarios evolve. Empirical significance emphasizes the importance of integrating ABAC with blockchain for adaptive policy management, in line with adaptive security frameworks. The discovery of this gap in understanding policy adaptation dynamics underlines the necessity of flexible access control systems in rapidly changing emergency contexts.

4.3 Improvement in Efficiency and Reliability in Data Sharing

This discovery confirms Hypothesis 3, which shows that blockchain-based systems improve the efficiency and reliability of data sharing in emergency management. Analyzing the system logs and the stakeholder feedback from 2020 to 2023, it shows that blockchain implementations contain much faster rates of data-sharing and higher uptime for the system compared to traditional systems. The independent variables contain blockchain's decentralized data exchange mechanisms, while dependent variables are focused on the efficiency metrics of data transfer rates and system availability. Correlation reflects the fact that blockchain reduces bottlenecks and provides seamless information flow in operation. Empirical significance supports theories on decentralized system efficiencies, reinforcing blockchain's role in optimizing data sharing. This finding addresses gaps in empirical evidence for blockchain's efficiency benefits and highlights the potential of decentralized systems to improve emergency management responsiveness.

4.4 Risk Mitigation in Blockchain-Based Emergency Management

This finding supports Hypothesis 4, as blockchain is effective in mitigating risks associated with single-point failures and unauthorized access in emergency management. System reliability reports between 2020 and 2023 have indicated low occurrences of system failures and unauthorized access in blockchain systems. Independent variables that have major importance are consensus mechanisms used by blockchain and its decentralized architecture. The dependent variable is risk metrics such as failure frequency and violation of access rates. This suggests that the correlation indicates robust framework by blockchain against any single-point failures and reduces the possibility of unauthorized access. Empirical significance aligns with risk management theories, as blockchain's value is furthered in ensuring system resilience. By filling gaps in understanding the risk mitigation capabilities of blockchain, this finding further emphasizes the critical role decentralized architectures play in maintaining secure and reliable emergency management operations.

4.5 Viability of Hyperledger Fabric in Real-World Applications

This finding supports Hypothesis 5, where Hyperledger Fabric is proved to be viable as a framework for secure and scalable data sharing in emergency management. Hyperledger Fabric implementations from 2020 through 2023 show effective integration and scalability in the system evaluations and case studies within the diverse emergency scenarios. The independent variables include modular architecture and consensus protocols of Hyperledger Fabric, while dependent variables are the implementation metrics, such as the adaptability and scalability of the system. This correlation shows that, indeed, Hyperledger Fabric offers a flexible and robust platform that can support increasingly urgent and complex data sharing necessities in an emergency. Empirical significance points out the fact that there is practical applicability of Hyperledger Fabric in real-world contexts, which aligns with the theories on modular system architectures. By filling gaps in the real-world evaluation of blockchain frameworks, this finding suggests that Hyperledger Fabric can help improve emergency management through secure and scalable solutions.

5. Conclusion

This synthesis study compiles the results of the role blockchain plays in strengthening data security, policy adaptation, and system reliability in emergency management. In fact, it positions it as one of the major enablers of secure and efficient data sharing. The research still shows much progress but remains limited to reliance on the data that exists already and challenges of accessibility in regions that are less developed. Future research should consider varied blockchain frameworks and their impact under different emergency conditions in order to refine the understanding of decentralized data governance. This would bridge the current gaps and optimize the strategies for secure data sharing in emergency management and would make the practical applications of blockchain technology more applicable to a global context. With such efforts in place, future research could provide more inclusive and elaborate insights into how blockchain adds to secure and efficient emergency management through various contexts.

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