Designing and Implementing a Custom Blockchain for Spatial Data Sharing

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Abstract

With the expansion in the volume and variety of spatial data and the increasing reliance of geospatial information systems (GIS) on web-based platforms, the need for secure, transparent, and trustworthy structures for data storage and exchange has become more pressing than ever. Conventional centralized architectures, despite their ease of implementation and management, face challenges such as centralization, security vulnerabilities, and reduced accessibility. This study investigates the utilization of blockchain technology as a decentralized and tamper-resistant platform to address these challenges. First, the study reviews the related literature on the integration of blockchain with GIS and analyzes the shortcomings of existing blockchains in meeting the specific requirements of this domain. Then, an initial design of a blockchain-based GIS is presented, with its architecture specifically tailored to the sharing of spatial data within this framework. In this system, the Well-Known Binary (WKB) format is selected for storing spatial data, and a simplified Proof-of-Work consensus algorithm is employed to coordinate among nodes. The system is implemented at the proof-of-concept level using the Python programming language and the Flask framework. The proposed approach can serveas an effective step toward the development of dedicated blockchains for the exchange and sharing of spatial data and provides a suitable foundation for future research aimed at enhancing the scalability and performance of GIS.

1. INTRODUCTION

Today, spatial data is considered one of the most vital sources of information, playing a significant role in decision-making and the provision of infrastructural services (Chrisman, 2002). With the increasing generation of such data from various sources and the growing use of Geographic Information Systems (GIS), the need to improve processes and make appropriate choices regarding infrastructure and development approaches has become a major concern for users and responsible institutions (Li et al., 2020). A considerable portion of modern GIS platforms are developed based on centralized web architectures. While this type of architecture offers advantages such as ease of implementation, centralized management, and unified control of resources (Fu and Sun, 2010), it also entails serious limitations and challenges in practice. Centralization not only increases the risk of data misuse and manipulation of sensitive information but also reduces accessibility during critical situations and decreases transparency in data exchange processes (Zhang et al., 2020). These issues, especially at larger scales or in environments with institutional diversity or high data sensitivity, have more pronounced negative impacts on system performance and user acceptance (Gong et al., 2004). In this context, emerging technologies associated with Web 3.0—particularly blockchain technology—offer valuable capabilities for addressing these challenges by leveraging decentralized architectures, thereby improving the trustworthiness and security of such systems (Wehn de Montalvo, 2002). Nevertheless, current blockchain infrastructures in use today—such as Bitcoin and Ethereum, which were fundamentally designed for financial applications and general-purpose development—despite their technical advantages, have proven inefficient in certain domains (Ramadoss, 2022). This inefficiency is primarily due to challenges such as low transaction throughput, high network usage costs, lack of formal standards for specialized fields, legal and security limitations in using public and private infrastructures, and implementation barriers at various levels(Wohrerand Zdun, 2021). In the domain of spatial information systems, due to the dynamic nature of the data, the high volume of processing, and the need for compliance with specific standards, these challenges—depending on the type of application—can present serious obstacles to practical deployment and utilization. This paper, taking into account such shortcomings, aims to conduct a structural examination of both domains at a foundational level and present an initial design for the development of a blockchain-based spatial information system. The proposed platform is designed from the ground up with the goal of storing and exchanging location-based data and is tailored toalign with the specific processes of this domain. Following a review and brief synthesis of existing research in this area, the paper introduces the fundamental concepts of blockchain and explains how it functions. Then, by analyzing the operational requirements and specific characteristics of spatial information systems, it identifies components of both technologies that can be optimized and integrated. Based on this analysis, a proposed framework is presented through an initial implementation. Fi- nally, the paper examines relevant operational challenges and considerations and offers suggestions for future research direc- tions to further develop and explore this domain.

2. A Review of Research on the Integration and Examination of Blockchain Technology in the Functional Domains of Geographic Information Systems

Numerous studies have explored the potential integration of blockchain technology with Geographic Information Systems (GIS). Each of these studies has approached the subject from a specific perspective, evaluating blockchain's capacity to enhance the efficiency, security, and intelligent utilization of such systems. A systematic review of academic literature indic-

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ates that the primary focus of these studies has been on examining the advantages, disadvantages, technical challenges, and practical applications of blockchain within this domain. In terms of benefits, most studies emphasize the opportunities that arise when blockchain replaces traditional infrastructure (Ali et al., 2021). Some articles have also analyzed the limitations that emerge from the convergence of these two domains (Tasatanattakool and Techapanupreeda, 2018). By considering both groups of literature together, users can gain a comprehensive understanding of the facets and implications of this integration before undertaking practical implementation and facing its associated challenges. Technical studies in this field have investigated the feasibility of implementing blockchain at various levels and through different strategies with a practical and detailed lens. Some of these studies, acknowledging the lack of a unified standard to date, have attempted to define the necessary standards within the field based on their own proposed frameworks (Cedeno Jimenez et al., 2022). Others have leveraged public blockchain infrastructures—such as Ethereum—to identify the specific needs of spatial information systems and to develop corresponding standards within those platforms, thereby creating their own decentralized geospatial applications (Benahmed Daho, 2020). Additionally, certain operational-level studies have focused on optimizing existing blockchain-based processes by addressing the unique requirements of the spatial data domain (Hojati, 2023). Other research efforts have examined the applications of this integration across different industries and everyday life, offering a broad vision to users and developers for the development of new infrastructures with diverse objectives (Mendi and Çabuk, 2020). In light of these considerations and the body of existing research, it can be concluded that most technical efforts in this domain have centered on defining standards, improving performance, or developing related applications based on existing public blockchains. However, far less attention has been paid to the necessity of designing and developing a dedicated blockchain tailored specifically to the unique requirements of spatial information systems. This is a critical area of inquiry, as optimizing blockchain development algorithms and aligning them with the needs of GIS can maximize the benefits of blockchain technology in this field while minimizing the drawbacks and limitations of public blockchains. Filling this gap is one of the most important tasks in current research, as the development and potential localization of such dedicated blockchains would enable their adoption by organizations and institutions that, for various reasons, cannot utilize public blockchain networks. This, in turn, would facilitate the deployment of blockchain-based GIS platforms across multiple levels of organizational infrastructure.

3. Structure of Blockchain Technology

Blockchain technology, as the foundation of decentralized systems, utilizes cryptographic techniques, consensus algorithms, and distributed architecture to provide a secure, transparent, and tamper-resistant environment for data. At its simplest definition, a blockchain is a type of distributed and immutable database that stores a collection of critical information or events in a series of interlinked blocks. Each block contains a set of transactions or events that, after validation, are added to the chain of blocks and protected through cryptographic mechanisms (Yaga et al., 2019). One of the key factors ensuring the resilience of this technology is its distributed structure. This structure relies on a network of nodes, each playing a role in storing, validating, and updating the information. Generally, nodes are classified into three main categories:

- Full Nodes (which maintain a complete copy of the blockchain)
- Light Nodes (which store only essential data required for basic operations)
- Specialized Validator Nodes (which actively participate in the consensus process and block production)

In addition to the structure and roles of nodes, one of the most critical factors ensuring data security in a blockchain network is the advanced cryptographic mechanisms applied at both the block and transaction levels. Each block is protected using a unique code known as a hash—a component that ensures even the smallest alteration in the block's data results in a completely different hash, which can be easily detected by the network. At the transaction level, security is maintained through the use of digital signatures, which enable verification of ownership and authenticity of the transmitted data. Like hashes, digital signatures play a crucial role in preserving data integrity and trustworthiness. Thanks to these mechanisms, it becomes virtually impossible to alter data without the knowledge of other nodes, thereby forming a secure and immutable chain of information across the network. Once signed transactions are submitted by users, they are initially stored in the memory pool (Mempool) of the nodes before being added to the main blockchain. At this stage, validator nodes are responsible for verifying the validity of the signatures, the structure of the transactions, and their compliance with network rules. Only those transactions that successfully pass this validation process are permitted to enter the blockchain. Ultimately, the validated transactions are packaged into a new block, which is then appended to the chain by one of the selected nodes based on the network's consensus algorithm. This algorithm, as a mechanism for achieving agreement among nodes, allows for the ordering, verification, and acceptance of information. It is this process that forms the foundation of trust within decentralized environments. In summary, a deep understanding of blockchain's core components is essential for designing and implementing specialized blockchain-based systems. In this context, Figure 1 visually illustrates an overview of the processes and interactions between components in blockchain systems (Drescher, 2017).

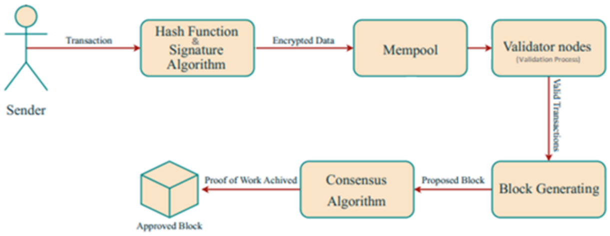

Figure 1. General structure of component functions and interactions in a blockchain-based system.

4. Functional Analysis and Specific Requirements of Geographic Information Systems

Geographic Information Systems (GIS), as a foundational infrastructure for the collection, storage, processing, and analysis of location-based data, play a vital role in resource management and the delivery of public services in spatial domains (Li et al., 2024). These systems provide a platform through which spatial data from various sources can be aggregated, combined with descriptive (attribute) information, and presented in the form of maps, reports, and spatial analyses that are comprehensible and actionable for decision-making purposes. The functionality of such systems is typically categorized into three main levels: data visualization, data querying, and spatial analysis (Costantini and Thompson, 2023). To achieve these capabilities, every GIS is built upon a coordinated interaction among key components such as hardware infrastructure, software platforms, spatial and descriptive data, defined operational processes, and end users. The synergy between these components is essential for ensuring effective and sustainable system performance. These components, when integrated into a purposeful architecture, establish a framework for interaction between data and users. Any disruption or inefficiency within this cycle can result in reduced analytical accuracy, diminished trust, and compromised decision-making processes that rely on spatial information. In this context, with the advancement of web technologies, WebGIS platforms have emerged as a more advanced evolution of traditional GIS systems. These platforms enable access to, processing of, and sharing of geospatial data over the internet (Agrawal and Gupta, 2017). WebGIS systems provide functionalities such as map visualization and spatial processing through server-based and web-accessible environments. Effective utilization of WebGIS across various levels demands reliable, scalable structures built upon recognized standards. Given the inherent sensitivity and growing demand for enhanced security and transparency in handling spatial data, existing traditional architectures must evolve toward more resilient and tamper-proof paradigms—namely, decentralized architectures. In this regard, technologies such as blockchain—which are fundamentally built upon such decentralized models—offer unique features that can address some of the existing limitations in current GIS platforms. Therefore, redesigning WebGIS systems using infrastructures based on decentralized architecture patterns may offer a strategic solution for the future of spatial data management (Al Ridhawi et al., 2021). This transformation could enhance security, transparency, and trust in spatial systems, ensuring they are better equipped to meet the demands of modern spatial data applications (Le and Hsu, 2021).

5. Proposed System Design

Given the existing challenges and infrastructural limitations in managing geospatial data, this section introduces an innovative approach based on blockchain technology to enhance the efficiency, transparency, and trustworthiness of Geographic Information Systems. It is important to note that developing a dedicated blockchain from the ground up is a complex process that requires extensive technical infrastructure and interdisciplinary collaboration across various domains. Therefore, the primary aim of this research is to identify and optimize specific components within blockchain architecture that can be aligned with the unique requirements of spatial data systems. The proposed system is primarily focused on enabling the collection, recording, and sharing of spatial data over the web. Accordingly, a simplified blockchain structure is considered—one that facilitates the decentralized storage and exchange of geospatial data among network participants. In this regard, by selecting a suitable blockchain framework and applying targeted modifications to its underlying logic, a specialized platform for geospatial data exchange has been designed. In other words, the goal of this research is to present a proof of concept for such a system, which not only defines the design framework but also lays the groundwork for future developments and deeper investigations. The following part of this section will describe the development stages of the system's core components and explain how the system functions in practice.

5.1 Block Structure Definition

One of the most critical aspects of designing a blockchain-based system is determining an appropriate structure for transactions and network blocks. The importance of this task lies in the fact that choosing an inefficient format for data transmission and storage can lead to unnecessary data bloat, increased processing complexity, and ultimately, reduced network performance and throughput. These issues become especially problematic in blockchain systems that require high scalability, where even small inefficiencies can significantly impact overall system functionality. To define an optimized format for transactions containing geospatial data, reviewing existing and proposed standards in this field is a logical and effective approach. Although no definitive and universally adopted standard for registering geospatial data on the blockchain has been established to date, some organizations and companies have made notable efforts in this direction. For instance, the Open Geospatial Consortium (OGC)—a leading authority in the field of geospatial information—has examined the capabilities of the FOAM protocol in one of its publications (Gobe Hobona, 2018). This protocol, which runs on the Ethereum blockchain, utilizes the Geohash system (a compact and approximate method of location encoding) to encode spatial positions (FOAM Whitepaper, 2018). In contrast, the OGC has also introduced another standard known as Well-Known Binary (WKB), developed under the OGC/ISO framework (Benet, 2014). In this format, geospatial data is stored as byte strings, which allows for high precision, the representation of complex geometric objects, and compatibility with various geospatial processing tools. Based on such evaluations, this study adopts the WKB format as the preferred option for recording geospatial data within the proposed blockchain system. This is due to WKB's high precision in representing spatial information, efficient memory usage, and its flexibility for future developments and compatibility with other standards. Furthermore, each block in a blockchain network requires a set of fundamental metadata to function correctly and maintain secure links with adjacent blocks. This typically includes:

- the previous block hash (Previous Hash)
- the timestamp of block creation
- a nonce value (especially when using consensus algorithms such as Proof of Work)
- a unique identifier for the current block

These components, together with the geospatial data payload, form the core structure of each block and ensure the coherence and security of the blockchain. Figure 2 schematically illustrates the general structure of a blockchain block and its constituent elements.

5.2 Transaction Validation Mechanism

Before user-submitted transactions and their associated data can be recorded on the blockchain, it is essential to verify their correctness and compliance with predefined formats and standards. In the proposed approach, an input validation mechanism based on a predefined data schema is employed. Accordingly, data submitted by a user is accepted only if it conforms to the specified structure (WKB format). This method ensures structural consistency of the data and prevents the introduction of incompatible or malformed information into the blockchain cycle.

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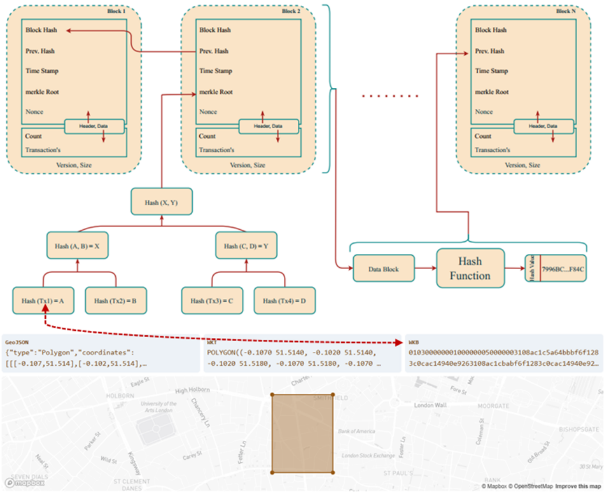

```
{"type":"Polygon","coordinates":
[[[-0.107,51.514],[-0.102,51.514],…
```

```
POLYGON((-0.1070 51.5140, -0.1020 51.5140,
-0.1020 51.5180, -0.1070 51.5180, -0.1070 …
```

```
0103000000010000000500000003108ac1c5a64bbbf6f128
3c0cac14940e9263108ac1cbabf6f1283c0cac14940e92…
```

Figure 2. Schematic representation of the components of a blockchain blocks.

5.3 Defining the Roles of Active Nodes in the Network

Another important aspect in designing blockchain-based systems is determining the roles of users within the network, which are defined according to the system's requirements. In the proposed approach, two functional roles for users are identified:

- Users who maintain the full blockchain and are responsible for synchronizing the network state
- Users who participate in the consensus process and the creation of new blocks

This role differentiation not only enhances scalability but also paves the way for developing more advanced consensus algorithms that require active user participation.

5.4 Consensus Algorithm

To coordinate among nodes and simulate the process of block registration in a decentralized environment, a simplified version of the Proof of Work method has been utilized. In this design, the overall structure of PoW is preserved, but to reduce computational complexity and align with the objectives of this project, the difficulty level of solving the problem is intentionally set lower. This approach allows the block mining process to be performed with minimal resource consumption, while the core consensus logic—based on competition to find a valid solution—remains intact.

5.5 Block Data Storage

After a new block is created (by the node responsible for solving the hash puzzle) and validated through the consensus algorithm, that block is added to the chain, and the data contained within it enters the storage process. Choosing an appropriate storage method plays a crucial role in ensuring data security, integrity, fast retrieval, and network scalability. Typically, data is stored in cryptographically secured key-value structures based on data trees, which not only allow rapid access but also guarantee immutability. Ultimately, this information is stored on the disk space of each node in the network. However, in this design, spatial data is kept temporarily in its original format in RAM. This approach is taken because the goal of this design is to provide an initial familiarity with the components and mechanisms of such systems, enable faster execution, and facilitate testing the overall system functionality.

6. Implementation Process Details

With the main framework of the proposed system defined in the previous sections, the initial implementation was carried out using the Python programming language along with the Flask microframework. In this system, users are able to send transactions containing spatial data, view the status of the blockchain, and participate in the transaction validation process through designated ports. To facilitate communication between users and the blockchain, the Postman tool was selected as the user interface; thus, users can connect to the system's APIs and, depending on their roles, either submit transactions or participate in the creation of new blocks. Figure 3 schematically illustrates the overall system architecture and the execution flow across its different components via several sequence diagrams. Additionally, Figure 4 displays a view of the system's deployed environment, highlighting details of the developed user interface's functionality.

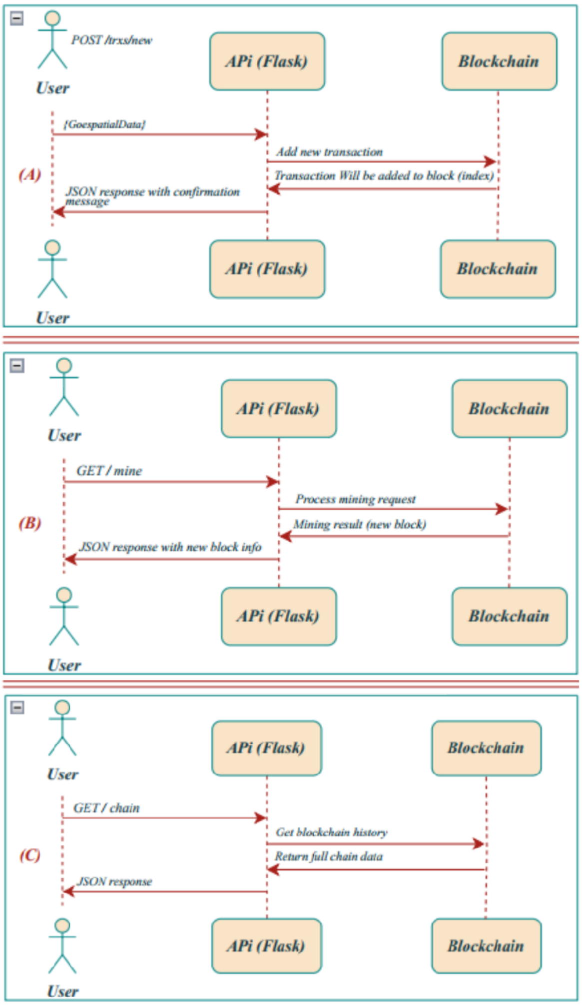

Figure 3. Schematic sequence diagrams demonstrating the interaction and execution flow across system components.

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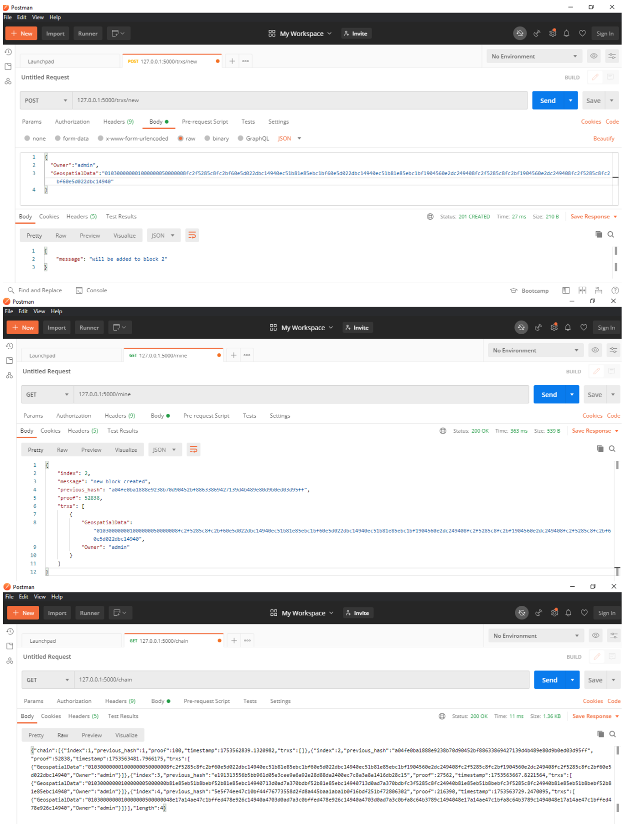

POST 127.0.0.1:5000/trxs/new

○ none ○ form-data ○ x-www-form-urlencoded ● raw ○ binary ○ GraphQL JSON

```
{
  "Owner":"admin",
  "GeospatialData":"0103000000010000000500000008fc2f5285c8fc2bf60e5d022dbc14940ec51b81e85ebc1bf60e5d022dbc14940ec51b81e85ebc1bf1904560e2dc249408fc2f5285c8fc2bf1904560e2dc249408fc2f5285c8fc2
   bf60e5d022dbc14940"
}
```

Status: 201 CREATED Time: 27 ms Size: 210 B

```
{
    "message": "will be added to block 2"
}
```

GET 127.0.0.1:5000/mine

Status: 200 OK Time: 363 ms Size: 539 B

```
{
    "index": 2,
    "message": "new block created",
    "previous_hash": "a04fe0ba1888e9238b70d90452bf88633869427139d4b489e80d9b0ed03d95ff",
    "proof": 52838,
    "trxs": [
        {
            "GeospatialData":
                "0103000000010000000500000008fc2f5285c8fc2bf60e5d022dbc14940ec51b81e85ebc1bf60e5d022dbc14940ec51b81e85ebc1bf1904560e2dc249408fc2f5285c8fc2bf1904560e2dc249408fc2f5285c8fc2bf6
                0e5d022dbc14940",
            "Owner": "admin"
        }
    ]
}
```

GET 127.0.0.1:5000/chain

Status: 200 OK Time: 11 ms Size: 1.36 KB

```
{"chain":[{"index":1,"previous_hash":1,"proof":100,"timestamp":1753562839.1320982,"trxs":[]},{"index":2,"previous_hash":"a04fe0ba1888e9238b70d90452bf88633869427139d4b489e80d9b0ed03d95ff",
"proof":52838,"timestamp":1753563481.7966175,"trxs":[
{"GeospatialData":"0103000000010000000500000008fc2f5285c8fc2bf60e5d022dbc14940ec51b81e85ebc1bf60e5d022dbc14940ec51b81e85ebc1bf1904560e2dc249408fc2f5285c8fc2bf1904560e2dc249408fc2f5285c8fc2bf60e5
d022dbc14940","Owner":"admin"}]},{"index":3,"previous_hash":"e191313556b5bb961d05e3cee9a6a92e28d88da2400ec7c8a3a8a1416db28c15","proof":27562,"timestamp":1753563667.8221564,"trxs":[
{"GeospatialData":"01030000000100000005000000b81e85eb51b8bebf52b81e85ebc14940713d0ad7a370bdbf52b81e85ebc14940713d0ad7a370bdbfc3f5285c8fc24940b81e85eb51b8bebfc3f5285c8fc24940b81e85eb51b8bebf52b8
1e85ebc14940","Owner":"admin"}]},{"index":4,"previous_hash":"5e5f74ee47c10bf44f76773558d2fd8a445baa1aba1b0f16bdf251bf72806302","proof":216390,"timestamp":1753563729.2470095,"trxs":[
{"GeospatialData":"01030000000100000005000000048e17a14ae47c1bffed478e926c14940a4703d0ad7a3c0bffed478e926c14940a4703d0ad7a3c0bfa8c64b3789c1494048e17a14ae47c1bfa8c64b3789c1494048e17a14ae47c1bffed4
78e926c14940","Owner":"admin"}]}],"length":4}
```

Figure 4. Overview of the deployed system environment and operational features.

7. Advantages and Disadvantages of the Proposed System

The proposed system is designed and implemented to address existing shortcomings and leverage decentralized architectures in the development of spatial information systems. Among the most significant advantages of this system is its effort to enhance the security of spatial data. The use of cryptographic algorithms and the storage of information in block formats prevent data from being altered or deleted without undergoing the network's consensus process. This feature is highly valuable in terms of preserving data authenticity and integrity. Additionally, by eliminating intermediary entities and enabling the direct recording and sharing of data on the blockchain, user independence is increased, and data ownership is returned to its rightful owners. Moreover, the decentralized architecture of this system ensures that there is no single point of failure, and the network's continued operation does not rely on any specific entity or server. This feature is especially important in environments with low trust levels or critical conditions. Furthermore, the ability to trace changes, transparency in data history, and transaction auditability are among the other strengths of the designed system. However, this approach faces challenges such as the complexity of developing dedicated blockchains and the need for extensive technical expertise. In addition, the system's performance at a large scale and with dynamic spatial data requires a more detailed framework design and an optimized process. Resource consumption and processing delays, particularly when compared to centralized databases, are also potential limitations. Despite these challenges, providing a conceptual framework for the development of specialized blockchains in the spatial data domain represents an effective step toward opening new research and practical horizons in this field and can play a significant role in future studies of spatial data infrastructures.

8. CONCLUSIONS

In this paper, while reviewing and analyzing the performance of spatial information systems and clarifying their specific requirements, the importance of managing spatial data and the existing challenges in this domain were addressed. Additionally, the necessity of leveraging modern technologies such as blockchain to enhance security, transparency, and trustworthiness in these systems was emphasized. Considering the limitations and problems of centralized infrastructures and the inefficiency of public blockchains in certain operational processes within the spatial information domain, the design and development of a dedicated blockchain tailored to the specific needs of this field was proposed as an innovative solution. The initial framework presented in this study, by utilizing existing standards in optimizing key blockchain modules, enables decentralized storage and exchange of spatial data within a secure and efficient environment. Moreover, by defining clear roles for nodes and optimizing the consensus algorithm, an effective step has been taken toward reducing operational complexity and improving the system's scalability. Nevertheless, this research represents merely a proof of concept and requires extensive further investigation to address remaining operational and practical challenges. Future efforts focusing on enhancing performance, security, compliance with international standards, and multi-faceted evaluation of the system can significantly improve the applicability of this technology in the spatial information domain. Ultimately, the integration of blockchain technology with spatial information systems presents unprecedented opportunities for transforming spatial data management and increasing the trust of users and organizations. This can substantially contribute to improving geographic decision-making and the development of intelligent infrastructures.

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