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Geospatial Blockchain: review of decentralized geospatial data sharing systems

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Abstract. Blockchain technologies are driving the internet infrastructures into a transformation from Web 2.0 to Web 3.0. This remodels the internet foundations from a centralized approach, where data is hosted by a single actor, to a decentralized one in which data is distributed among peers in a network. Thanks to blockchain technologies, the evolution from centralized to decentralized applications (dApps) eliminate single points of failure, data censorship and data tampering. This transformation is not only important in the financial sector, where the technology is more evolved, but also in geospatial crowdsourcing activities. The objective of this work is to perform a literature review of current blockchain technologies used for sharing and crowdsourcing activities involving geospatial data. This study serves as a starting point for future works where the main purpose is to develop a geospatial sharing blockchain platform. At the present, two platforms have been developed for this purpose, FOAM and D-GIS. The former is a fully deployed implementation whose objective is to create a crowdsourced map. The latter is a platform designed to share geospatial studies publicly, however, it is only developed conceptually and not deployed. Additional to these works, other blockchain data sharing examples exist and are reviewed in this study as a baseline for future developments in the geospatial area. The output of this research indicates that it is feasible to use blockchain technology for the development of a crowdsourcing geospatial data-sharing platform.

Keywords. Geospatial data sharing, blockchain, crowdsourcing, open GIS

1 Introduction

Nowadays blockchain technologies have become an increasingly popular topic. This has happened mostly in the financial sector with cryptocurrencies, and at a smaller scale also in other areas (Sladić et al., 2021) such as medicine, with medical records registry, (Vazirani et al., 2020); and art with the Non-Fungible Tokens (NFT) (Kugler, 2021). The implementations of blockchain technologies are present in both the public and private sectors. An example of its use in the public sector is Estonia's government, where most of its provided services have been digitised and secured through an infrastructure called KSI Blockchain (Martinson, 2019; Sullivan and Burger, 2017). The use of blockchain in the private sector is implemented through the development of decentralized applications and blockchain-enabled business models, such as the unification of critical business activities by providing a relationships channel with business partners or distribution of revenue across the value chain (Dutra et al., 2018). The range of applications in both public and private sectors reveals that blockchain infrastructures have received considerable interest in the research community (Zeadally and Abdo, 2019).

Blockchain is a technology that solves the problem of creating trust between parties in distributed storage. It consists of a chain of data packages called blocks, each block contains a set of transactions that are validated through the consensus of the participants in the system. Apart from transactions, the blocks also contain the hash value of the previous block. Hash values are strings of characters generated for a sequence of bits, so each block has a unique hash value. This means that if the smallest variation happens to any of the blocks, its hash would change, affecting in turn the next blocks and breaking the chain (Nofer et al., 2017). The main appeals of using the blockchain as a data-sharing platform are (Di Pierro, 2017):

- Decentralization: Data is not provided by a single host but is distributed among peers.
- Immutability: It is not possible to modify data once it has been created.
- Transparency: Transactions are registered in blocks that are published openly in a distributed ledger.

Additionally to these characteristics, data traceability has recently become of interest as a security layer in blockchain applications. GeoBlockchain has been defined by some authors as the combination of both blockchain and location intelligence to identify spatial trends of blockchain transactions (Papantoniou, 2020). In this sense, geospatial technologies are used to track the geographical and spatial behaviours of users inside the blockchain (Papantoniou and Hilton, 2021). Therefore GeoBlockchain's principal purpose is not of sharing geospatial information as a data structure, but to verify the geographic provenance or source of blockchain transactions (Bolger, 2019; Papantoniou, 2020). In the remaining part of this work, Geospatial Blockchain will be used as the term that describes the use of the blockchain infrastructure whose main purpose is to share geospatial data.

Sharing data and crowdsourcing is a predominant concern in geospatial information sciences because it provides enriched content that can only be achieved by the work of a community. The best example of this is OpenStreetMap, a user-generated mapping project considered the largest existing geospatial database (Brovelli et al., 2020). Developing a project of such kind on a decentralized network like the blockchain can provide the system with decentralization, immutability and trust.

The purpose of this work is to carry out a state-of-the-art literature review of blockchain geospatial data sharing infrastructures that can serve as a starting point for future developments on this area. Due to the limited number of Geospatial Blockchain implementations, examples outside the geospatial information science area will also be described as lessons learned and for filling the gaps that current developments have left.

2 Non-Geospatial Data-Sharing Systems

Decentralized applications (DApps) are applications deployed on a decentralized network (i.e the blockchain) by combining smart contracts and a user interface (Tsampas, 2022). Smart contracts were initially conceived in 1994 by Szabo (Mohanta et al., 2018), as a computer protocol that executes in terms of an agreement between two parties, minimizing the need for intermediaries (Cong et al., 2019). A DApp has the capability of running scripts in the blockchain, but some blockchain infrastructures are not capable of achieving this task. An example is Bitcoin, the first blockchain infrastructure conceived as an electronic cash system (Nakamoto, 2008), whose scripting language is capable of only performing basic value transfers. It was not until 2014 that Ethereum was created as a "next-generation smart contract and decentralized application" platform (Buterin, 2014) which allowed the execution of code. Today, Ethereum is the most used smart contract blockchain. It employs the use of Turing-complete language capable of performing general-purpose computations (Lone and Naaz, 2021) beyond Bitcoin's basic value transfer. But Ethereum is not the only one with this capability. Alternatives that execute smart contracts such as Cardano (Hoskinson, 2017) and Solana (Yakovenko, 2017) are also available.

The following examples of DApps can be taken into consideration as case studies, even if these are not focused on geospatial data sharing. These examples provide an insight into sharing data structures through the blockchain network that can be in the future translated to geospatial data.

Due to the nature of the blockchain (a ledger that works as a lightweight transaction registry), one of the biggest challenges of using the blockchain infrastructure is sharing large files. Therefore a work for blockchain-enabled sharing of big data is of relevant discussion in this research. This development consisted of a blockchain-based big data-sharing platform that can address the data-sharing needs of several users. The sharing methodology ensures not only the efficient transmission of information but also that people view and agree on the information in the design data transaction process. Data sources are saved on the PCs of different users employing a retrieval methodology and Tamper-Proof Mechanism (TPM). This work's main contribution to the Geospatial blockchain is the distributed system that can be taken as an example to share large amounts of data among peers, allowing users to query multiple pieces of information in the ledger (Yang et al., 2020).

Additional to sharing large files through the blockchain, a challenge is to have fine access control over the distributed data. According to Yang et al. (2020), this can be achieved through a combination of infrastructures additional to the blockchain such as the InterPlanetary File System (IPFS) and Attribute-based encryption (ABE). The IPFS is a peer-to-peer content-addressable distributed file system that aims to connect computing devices to a single file system. It's a community-driven open-source project with reference implementations in Go and Javascript and a global user base of millions (Psaras and Dias, 2020). When uploading a file into the IPFS the user obtains a unique cryptographic hash string through which the file can be retrieved. Content-addressed systems like the IPFS, search directly for the content the user requests, opposite to conventional location-addressable where the user has an address and asks the system to extract whatever content is present in that location. ABE enables a system to use attributes instead of IDs. By defining an access policy, the data owner can assign user groups that can access the data; only users whose qualities match the access policy can access the data. This system architecture prooves to solve the problems of a single point of failure (through IPFS decentralised storage), access authorization (by implementing ABE) and decentralized ciphertext search using the blockchain network (Yang et al., 2020).

3 Geospatial Blockchain Applications

Up to the moment of this writing, only two blockchain applications have been created, dedicated exclusively to sharing geospatial data: FOAM and D-GIS which will be described in the next sections. It is worth mentioning that although both of these implementations are completely developed conceptually, only one has been deployed. This section includes a review of these two platforms.

3.1 FOAM

FOAM is a decentralised open protocol application designed to create a crowdsourced map. This software has been fully implemented and is currently active on the developer's website (https://foam.space). FOAM is built on top of the Ethereum network and it tries to solve three problems in geospatial data sharing environments: location encoding standards, user experience for spatial applications and verification of the authenticity of location data (FoamspaceCorp, 2018).

To solve the location encoding problem, FOAM uses CryptoSpatial, a Discrete Global Grid System (DGGS). DGGSs are area-preserving reference systems that hierarchically partition the Earth into cells (e.g. hexagons or triangles) (Sahr et al., 2003). The system used by FOAM is the Crypto-Spatial Coordinates (CSC), a protocol based on geohash (figure 1) (Singh, 2022) as a reference system, in combination with Ethereum blockchain addresses. The aggregation of these two encoding systems allows both to locate an observation in the blockchain and on the Earth's surface seamlessly.

Figure 1. Graphical representation of the Geohash. For the first hierarchical level, the Earth's surface is first bisected into two areas (parent level), for subsequent levels the parent levels are bisected into two areas. Edited image, original taken from section V, figure 5 of Suwardi et al. (2015)

The user experience problem rises from the need to visualise and interact with geospatial data. Current solutions do not integrate the necessary software for extracting data from the blockchain and representing them on a map. Therefore FOAM developed a Spatial Index and Visualiser (SIV). The SIV uses the CSC encoded addresses to query and geolocate smart contracts and display them on a web application. The application allows users to interact with the observations to perform data validation of points uploaded by other users (FoamspaceCorp, 2018).

The SIV (figure 2) is divided into four major components, the graphical interface (red), the FOAM smart contracts (yellow), the Ethereum blockchain (green) and the indexing and API (blue) that extracts the geospatial data to be presented on the graphical interface.

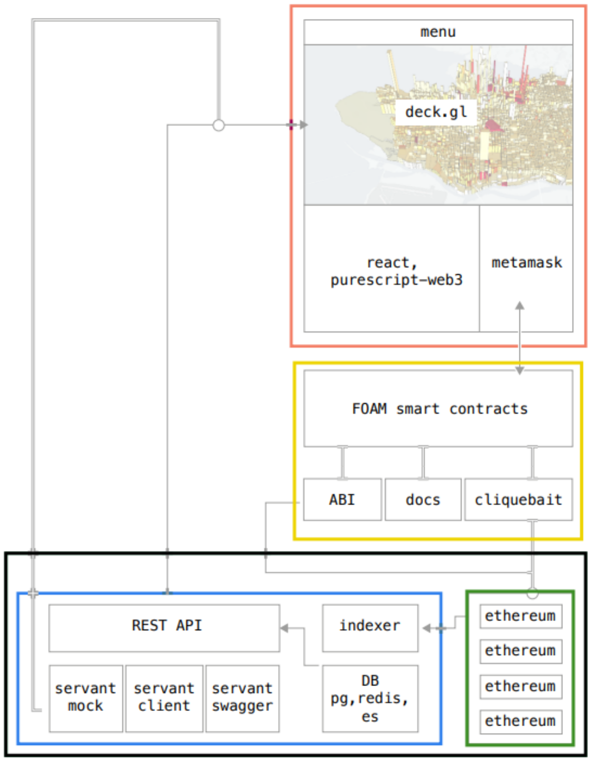

Figure 2. The SIV, is divided into four major components, the graphical interface (red), the FOAM smart contracts (yellow), the Ethereum blockchain (green) and the indexing and API (blue). Edited image, original taken from section 'Properties of the Spatial Index and Visualizer' of FoamspaceCorp (2018).

The verification of the authenticity of location data is the final result of the location encoding and the SIV user interface. Employing these tools, the user can validate observations (that other users have uploaded) through a voting mechanism. The mechanism rewards the users that help curate the data contents by awarding tokens. Users can either challenge points of interest or validate or reject them (FoamspaceCorp, 2018).

The integration of these three components (location encoding standards, user experience for spatial applications and verification of the authenticity of location) makes the FOAM system unique. Even though the ultimate goal of this project is not to share other kinds of geospatial infrastructures (e.g. raster data or QGIS projects), it has demonstrated the feasibility of developing a Geospatial blockchain.

3.2 D-GIS

D-GIS is a conceptual blockchain infrastructure that is designed to share geospatial data. Although it has not been publicly deployed, it is fully developed conceptually. The main objective is to provide a platform that enables geologists and engineers to share geospatial data and their work securely. The problems this platform is trying to solve are related to ownership rights and a democratic ecosystem. The development implements an Ethereum blockchain infrastructure that mimics a decentralized and immutable economic market that promotes competition between authors. Competition is achieved utilizing a ranking mechanism, where users are assigned tokens proportional to the size of their contributions. Users can also cast votes on contributions of other users, having a voting strength equivalent to their reputation. To avoid excessive voting and as a consequence, domination of a single user, voting has a small penalization that lowers the user's reputation (Leka et al., 2019).

D-GIS architecture consists of two main elements that can be categorized as 'on-chain' and 'off-chain'. On-chain elements are those components related to the blockchain infrastructure which are classified as Local Storage, Individual Accounts and Global Storage. The local storage (figure 3a) groups the work of a user that is uploaded on the blockchain with characteristics such as status, rating, owner, description and other data. The individual account (figure 3b) is the structure for storing the user's work uploaded and its reputation. The global storage (figure 3c) identifies, stores and indexes global data of the works published on the network (Leka et al., 2019).

Off-Chain elements (figure 4) refer to the client-server application module that interfaces with the smart contracts. The key component in this structure is the GoServer, an application layer that allows users to connect with the on-chain elements. Multiple users are capable of connecting contemporarily to the application module through their personal devices. Additionally, the D-GIS employs a Deep Learning algorithm for data categorization, that allows the system to examine the uploaded projects, detect similarities and detect plagiarism or redistribution (Leka et al., 2019).

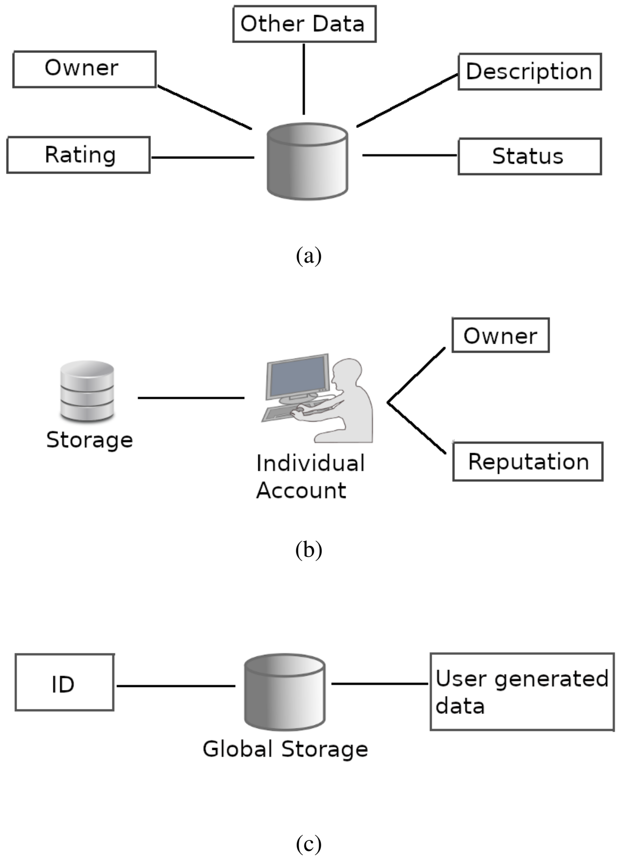

Figure 3. D-GIS on-chain elements functional diagrams composed of three elements a) the local storage. b) individual accounts c) global storage. Images based on section IV, subsection A of Leka et al. (2019)

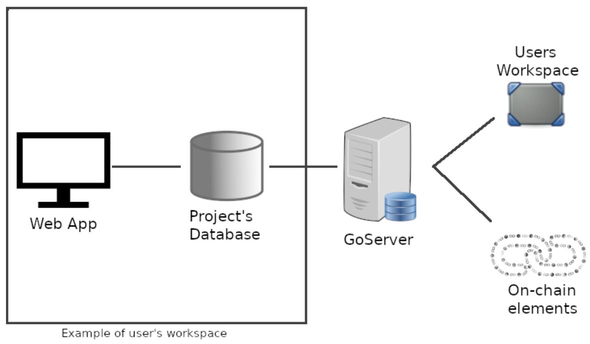

Figure 4. Functional diagram describing D-GIS off-chain elements. Images based on section V, subsection A of Leka et al. (2019)

3.3 Platforms Comparison and Analysis

Both FOAM and D-GIS offer an innovative approach to the Geospatial blockchain predicament. On the one hand, FOAM is an already-deployed solution constrained to providing a crowdsourced map. On the other hand, D-GIS is designed to share geospatial data, not limited only to 'single points' but also geospatial projects. The biggest limitation of D-GIS is that due to the lack of deployment and documentation, the feasibility still needs to be demonstrated and the design of the application is yet to be completed.

Another aspect that still needs to be discussed is the selection of the blockchain network. Both FOAM and D-GIS are based on Ethereum due to its popularity and ability to deploy smart contracts, also at the moment in which these applications were developed, it was still feasible to be used in terms of cost. Choosing the blockchain network is a crucial task that impacts directly the usability of a DApp. The choice cannot be only limited to the presence of smart contracts and the usability of the programming language, but also the cost of transactions. Currently, using the Ethereum network implies paying fees that are thousands of dollars higher than other networks (e.g. Cardano or Solana), making it infeasible to maintain a protocol of modest complexity in the Ethereum network (Unterweger et al., 2018). Even with the aforementioned limitation, these systems can serve as a precedent for building a fully functional geospatial blockchain data-sharing infrastructure.

4 Conclusion

This research paves the way for future works that have as a predominant focus the development of a Geospatial blockchain platform. Up to the moment of this writing, two Geospatial blockchain infrastructures have been fully developed conceptually (FOAM and D-GIS) and only one has been fully deployed (FOAM). FOAM and D-GIS present a novel solution to the Geospatial blockchain problem. The biggest constraint regarding these solutions is that the only application that has been deployed and tested is FOAM, but this is limited to being a ready-to-use solution with the only purpose of delivering a crowd-sourced map, not a space for sharing geospatial projects. D-GIS instead, is meant to share all types of geographic data, but it lacks deployment and documentation.

Taking as a baseline FOAM, D-GIS and projects developed in other areas that propose encouraging solutions, the results contribute to current research as the foundations for future geospatial de-centralized data sharing infrastructures that prioritise immutability, anonymity, consistency and consensus-based systems.

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