Interplanetary File System in Logistic Networks: a Review

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***Abstract*—Logistics 4.0 is a revolution based on information sharing and digitalization. Thus, Logistics 4.0 leads to the generation of huge amounts of data in short periods, and the data bloating problem must be addressed. One possible solution is the interplanetary file system (IPFS), which guarantees data replication and availability while limiting the storage of overlapping data. This study is the first literature review on IPFS and focuses on its application to the logistic sector. The main findings of this study are: the topic is gaining interest, but the solutions proposed in the literature were still in the early stages; IPFS was always coupled with the blockchain technology, and all of the authors used similar strategies to integrate them; the authors identified many advantages in the use of IPFS, but did not analyze in-depth the related disadvantages.**

***Index Terms*—Logistics 4.0, supply chain, IPFS, blockchain**

I. Introduction

Logistics 4.0 is a revolution based on information sharing and digitalization: the digitalization of physical assets is becoming cheaper and more accurate, and machine learning and granular computing techniques can automate the decision-making process, allowing the creation of optimized and autonomous cyber-physical systems [1].

In this context, many emerging technologies are finding increasing adoption. Blockchain and other distributed ledger technologies are used to track and trace logistic assets across the whole supply chain while guaranteeing the correctness, security, and availability of the data [2]. However, distributed ledger technologies are not efficient data storage solutions [3].

As supply chains are becoming more digital, they are also increasing the quantity of data produced, which can be difficult and expensive to store. One possible solution to this problem is the interplanetary file system (IPFS) [4].

IPFS is a peer-to-peer file storage solution that identifies documents by their content and not by their location. Thus, it reduces the storage of overlapping data and guarantees a high degree of redundancy, availability, efficiency, and cost-effectiveness [4]. Thus, IPFS could be a solution to the data bloating problem affecting digital supply chains.

Many supply chain solutions based on blockchain and IPFS are emerging. Tracking goods and other assets can ensure products' quality, simplify the identification of counterfeits and reduce the risk of litigation[3, 5, 6, 7, 8]. Moreover, demand forecasting [9] and inventory management [10] can benefit from the additional shared data. Score systems can discourage misconduct or unethical behaviors [11] and create new business models [12]. Although the number of studies on the topic is increasing, a review of state-of-the-art solutions, their strengths, and their issues is currently lacking.

This paper aims at analyzing the current adoption of IPFS in logistic and supply chain networks. In particular, we are interested in establishing the industrial readiness of the solutions proposed in the literature, their strengths, their weaknesses, and in identifying future research directions. The main findings can be summarized as follows:

- the adoption of IPFS is a trending topic in logistics and supply chain, but the current development of the state-of-the-art solutions is still in the early stages;
- IPFS is always coupled with blockchain, and the two technologies are always integrated in the same way. It could be interesting to explore the use of IPFS as a standalone technology;
- compared to centralized solutions, IPFS enhances the data replication and availability. Compared to blockchain, IPFS is a cheaper and more efficient data storage;
- IPFS problems (e.g., replication guarantees, data protection, data retrieval efficiency) are not sufficiently analyzed in the literature.

The remaining part of this paper is organized as follows: Section II summarizes the main concepts related to Logistics 4.0, blockchain, and IPFS; Section III describes the methodology used to perform the literature review; Section IV analyzes the current adoption of IPFS in logistics; Section V concludes the paper.

II. Background

A. Blockchain

Blockchain technology solves the trust issues among non-trusting parties and allows them to share data in a tamper-proof environment. Blockchain is a peer-to-peer network where some nodes share a common database [13]. The database is a ledger, as data can only be added to it. The ledger is composed of a sequence of blocks, each linked to its predecessor by a hash function. In particular, the header of a block contains the hash of its predecessor, and the body of a block contains the data. Each node has its full copy of the ledger. As the state of the database depends on what the majority of the copies store, and each node manages its copy independently from the others, only legitimate modifications of the ledger are possible (i.e., append operations). Modifications are named transactions and are processed by smart contracts. Smart contracts are tamper-proof computer programs that run on a blockchain.

B. Interplanetary File System

The interplanetary file system (IPFS) [4] is a peer-to-peer distributed file system. It combines ideas like distributed hash tables, block exchange protocols, version control systems, and self-certified systems. When a document needs to be stored in an IPFS network, it is divided into chunks and associated with a content identifier (CID). A CID depends only on the content of the document and not on where the document is stored. Consequently, identical documents have the same CID. When a peer downloads a document stored in the IPFS network, it also becomes a provider of that same document. At any time, peers can discard some of the documents to save storage space. Chunks that are common to different documents do not need to be replicated. Protocols like Filecoin [14] are built on top of IPFS and add an ulterior layer of incentivization and verification to reward peers for keeping copies of the document and for ensuring that they store the documents.

C. Logistics 4.0

At present, data can be collected, stored, and analyzed cheaply and efficiently. By opportunely installing IoT devices, it is possible to track and monitor objects in real-time and with a high degree of precision. Artificial intelligence and granular computing techniques can extract insightful information from the collected data and automate the decision-making process [15, 16]. The use of drones can automate on-field operations [17, 18]. Such technologies allow for the creation of autonomous and self-adapting cyber-physical systems. Distributed ledger technologies (e.g., blockchain) allow for securely and reliably sharing data among non-trusting parties, which could decrease logistic costs by simplifying bureaucracy, reducing the litigations, and improving demand forecasting [19]. Overall, digitalization and data sharing are radically transforming the logistic sector. Such transformations are identified collectively as the Logistics 4.0 revolution [1].

D. The Data Bloating Problem

The amount of data generated in the context of the Logistics 4.0 revolution can cause storage issues. This is particularly true when companies rely on blockchain technology to store data, as the blockchain ledger contains the data of all the peers, and it must be replicated across all of them [20]. Blockchain allows sharing data among non-trusting parties, but it is not an efficient storage technology. Conversely, IPFS is an efficient data storage, but it does not solve any trust issue. Thus, IPFS can be a solution to the data bloating problem, in particular when it is coupled with blockchain.

III. Research Questions and Methodology

As IPFS identifies documents and chunks by their content and not by their location, it allows reducing the storage space wasted: when adding a document to IPFS, only the chunks not already stored are persisted (if any). Thus, IPFS is a viable solution to mitigate the data bloating problem in Logistics 4.0, in particular when blockchain is also used.

We investigate the topic by posing the following research questions.

- Is IPFS finding adoption in logistics and supply chain? In which logistic sectors is IPFS finding the most adoption?
- What is the industrial maturity of the IPFS-based solutions in logistic and supply chain networks?
- Is IPFS always coupled with blockchain? How are the two technologies combined?
- Apart from addressing the data bloating problem, which are the main benefits of using IPFS in logistics and supply chain?
- What are the main issues in using IPFS? Is it possible to solve such issues?

To answer such questions, we selected the relevant contributions in the literature by executing the following research query on the title, abstract, and keywords of the documents in the Scopus database (last update: 23/02/2022): (ipfs OR ”interplanetary file*” OR ”interstellar file*”) AND (logistic* OR ”supply chain*”).

Of the resulting 45 documents, we discarded the non-English ones (two documents) and the conference reviews (two documents). By reading the remaining documents we discarded the non-relevant ones and restricted our investigations to 28 articles [9, 21, 22, 3, 23, 24, 25, 5, 26, 27, 28, 29, 30, 12, 31, 32, 7, 33, 34, 8, 11, 35, 36, 10, 37, 38, 39, 6].

IV. Review

In this section, we answer the questions posed in Sec. III.

A. Is IPFS finding adoption in logistic and supply chain networks? In which logistic sectors is IPFS finding the most adoption?

As demonstrated by the increasing number of articles published on the topic over the years (Fig. 1), the adoption of IPFS in logistics is a trending topic. In particular, researchers proposed IPFS for the agri-food and the pharma-med logistic sectors (Fig. 2). In agri-food supply chains, images can be helpful to prove the quality of the products. For example, the healthy growth of agricultural products can be certified through images [7]. Similarly, in many countries, purchasing drugs requires the exchange of receipts and prescriptions among doctors, patients, and pharmacists [33]. Thus, both sectors are characterized by the necessity of storing large documents, which justifies the adoption of IPFS.

B. What is the industrial maturity of the IPFS-based solutions in logistic and supply chain networks?

We classified the IPFS solutions proposed in the various documents in the following categories:

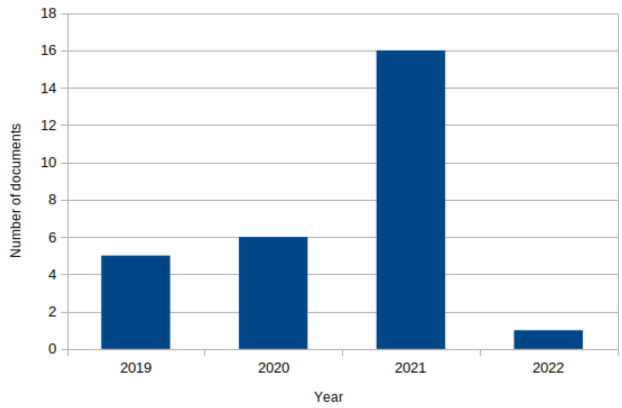

Fig. 1. Number of documents related to IFS and logistics as indexed in the Scopus database, categorized by year. Extraction date: 23/02/2022

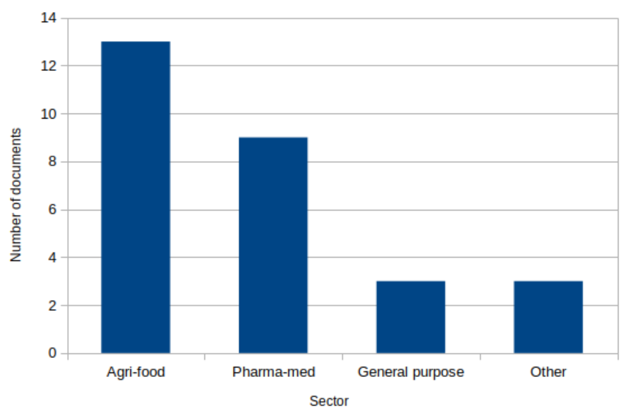

Fig. 2. Number of documents related to IFS and logistics as indexed in the Scopus database, categorized by logistic sector. Extraction date: 23/02/2022

- design, if the solution was only theoretical;
- implementation, if the solution was implemented but not tested;
- simulation, if the solution was tested through laboratory simulations;
- experimentation, if the solution was tested in a simplified on-field experimentation;
- production, if the solution was tested in a production-like environment and was ready to replace legacy systems.

As shown in Fig. 3, none of the solutions is production-ready, and almost all of them are in the design, implementation, or simulation class. Only two documents describe solutions in the experimentation phase [10, 7]. Probably, the industrial development was slowed down by the Covid-19 pandemic. Moreover, IPFS is not officially production-ready yet, although many protocols already leverage it (e.g., Filecoin [14]).

C. Is IPFS always coupled with blockchain? How are the two technologies combined?

IPFS was used as a standalone technology in none of the analyzed studies but was always coupled with blockchain.

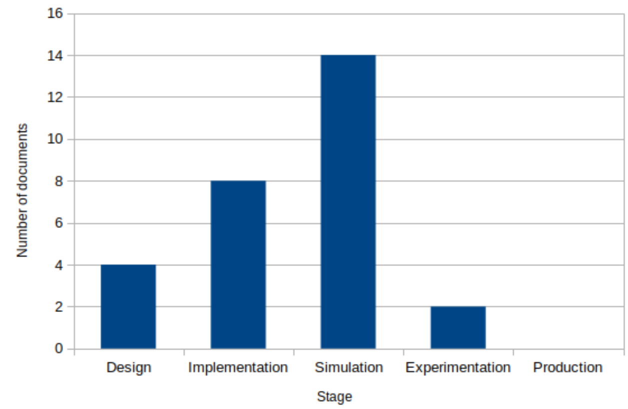

Fig. 3. Number of documents related to IFS and logistics as indexed in the Scopus database, categorized by industrial readiness. Extraction date: 23/02/2022

Moreover, all the studies used similar approaches to integrate the two technologies. In a first solution, a client stores the transaction data in IPFS and the relative CID in blockchain. As the CID identifies the content of the data, it is not possible to alter the data without also altering the CID. However, tampering with the CID is not possible once it is stored in blockchain. Thus, integrity is preserved, and storage is offloaded from the blockchain to IPFS. Alternatively, a smart contract running on the blockchain is in charge of receiving transactions, processing them, and storing the relevant data in IPFS. As in the other solution, the returned CID is stored in blockchain. The differences between the two approaches are shown in Fig. 4.

Although both solutions achieve the same result, the former is more efficient, as the storage smart contract only processes a small amount of data (i.e., the CID). Conversely, the latter one allows to pre-process the data before adding them to IPFS and can be used to enforce an access-control logic.

Other strategies for combining IPFS and blockchain are possible. For example, integrity can be preserved by storing the body of a blockchain's block in IPFS and the obtained CID in its header [20], but researchers did not adopt such strategies in logistics. Moreover, researchers did not investigate the use of IPFS in trusted logistic environments. Thus, such topics could be investigated in future research.

D. Apart from addressing the data bloating problem, which are the main benefits of using IPFS in logistic and supply chain networks?

Some of the analyzed papers underlined many benefits related to the use of IPFS.

Storing data in IPFS instead of using common centralized solutions (e.g., relational databases) enhances replication and availability [27], as IPFS relies on multiple peers. Moreover, as IPFS identifies data by its content, document versioning is automatically achieved by storing only the altered chunks of the newer versions.

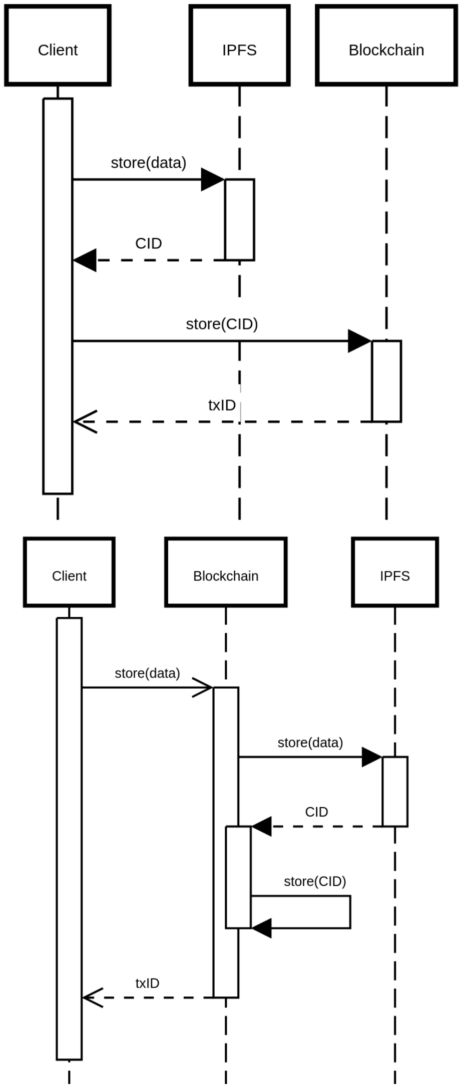

Fig. 4. IPFS and blockchain can be integrated by storing the data in IPFS and the relative CID in blockchain. Two strategies are possible: the client can be in charge of interacting with both IPFS and blockchain (top), or it can delegate the data storage to a smart contract running on the blockchain (bottom). Usually, the blockchain returns a transaction identifier (txID) that allows retrieving the CID.

Storing data in IPFS instead of blockchain reduces the blockchain size and improves the efficiency and scalability of the system [3, 27, 32, 8, 12, 24]. IPFS storage is cheaper than blockchain storage [8, 24, 34]. Moreover, by storing personal data in IPFS, only CIDs could be leaked from the blockchain [35]. Nonetheless, this point is a rather weak one, as there is no reason to believe that leakages from blockchain are more likely than leakages from IPFS. Moreover, according to the general data protection regulation (GDPR), a CID is personal data if it identifies some personal data. Finally, none of the papers discussed the advantages of IPFS over block pruning strategies. Through block pruning strategies, peers can discard some portions of or the whole body of the blocks, as only the headers are needed for verifying the correctness of the blockchain [13]. Thus, the benefits of IPFS over pruning strategies could be analyzed in future research.

E. What are the main issues in using IPFS? Is it possible to solve such issues?

Many of the studies did not analyze the issues related to IPFS in depth. The main concern addressed is data privacy, as IPFS has no built-in access control mechanisms. To this extent, role-based access control implementations of IPFS and encryption were considered possible solutions. The studies leaned towards encryption as the main privacy-preserving feature [31, 8, 7, 25, 36, 39, 27]. Nonetheless, this solution introduces additional challenges, as a way to decipher the data must be provided to the authorized parties. A possible solution is to transmit the decryption key to each party confidentially, but revoking access to the data is not possible once the decryption key is shared.

IPFS relies on the selfish behavior of peers to guarantee data availability and redundancy, which is often not enough in industrial environments. The allocation of storage space suffers from the same problem, as peers can selfishly increase or reduce the amount of storage space they offer. However, in industrial environments, a sufficient amount of storage space must be guaranteed. To circumvent such limitations, some studies argue that only non-critical data should be stored in IPFS [27, 26]. Moreover, economic incentives can reward peers for providing storage space, committing to store data, and answering queries. Proof of storage mechanisms are exploitable to check if peers fulfill their commitments [27]. Nonetheless, such incentives require the creation of digital currencies, which are uncommon even in blockchain-based logistic systems. Thus, future research could explore other non-economic strategies for incentivizing peers to provide storage space and store data. Moreover, the garbage in, garbage out problem should be further analyzed, as data integrity is of little use without data correctness [40].

V. Conclusion

Data sharing and digitalization are revolutionizing logistics. In this context, blockchain and other distributed ledger technologies are particularly interesting, as they allow to securely and reliably share data among non-trusting parties, with potential benefits in terms of cost reduction and process optimization. However, blockchain is an inefficient storage solution.

IPFS is a viable solution to the data bloating problem, and this study focused on its applications in the logistic context. According to the analyzed literature, IPFS was always coupled with blockchain. Moreover, IPFS-based logistic solutions are still in the early stages of development. Thus, many issues related to the adoption of IPFS must still be addressed. Nonetheless, researchers identified many advantages in the use of IPFS, including cost reduction and enhanced efficiency.

Future research will be aimed at extending the analysis of the IPFS technology to other fields and at investigating some of the research directions that emerged from the analysis of the literature.

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