Decentralized Drug Transaction Tracking: A Novel Hybrid Blockchain-IPFS Platform

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***Abstract*—Counterfeit drugs are a serious global problem that poses threats to public health. It occurs when falsified or counterfeit drugs are intentionally manufactured and introduced into the pharmaceutical supply chain, masquerading as genuine products. This is due to the complexity of the supply chain that involves independent entities. As a result, a drug transits through several stages before reaching the patient. Current drug management systems are centralized, thus creating data transparency and authenticity risks within the supply chain. To bypass this issue, we propose in this paper a novel hybrid and distributed drug transaction tracking platform that leverages a combination of the InterPlanetary File System (IPFS) protocol and Ethereum blockchain. Relying on IPFS guarantees the integrity of drug traceability data, while the blockchain ensures the authenticity of this data. We developed our platform and, through experiments, we prove that our method is more efficient, in terms of process costs, than the conventional blockchain-based drug tracking system.**

***Index Terms*—drugs, counterfeit, supply chain, IPFS, blockchain.**

I. INTRODUCTION

Medication monitoring is critical to ensure safe and reliable drug distribution under the right conditions. Since it extends to the whole supply chain, where numerous independent players such as pharmaceutical companies, distributors, and pharmacies, are involved, it is difficult to keep track of drug transactions. This situation is exacerbated by the typical centralized monitoring and competition among players, thus exposing drug data to alteration and falsification risks. Indeed, drugs can easily change ownership, be stored at different warehouses, or be transported over long distances and across different locations. This process can open the door to the fraudulent dissemination of counterfeit drugs into the supply chain. According to research conducted by the World Health Organization (WHO), an estimated 1 in 10 drugs in circulation in low- and middle-income countries is either substandard or falsified [1]. According to WHO, counterfeit medicine is “a medicine whose identity and/or origin is deliberately and fraudulently falsified”, whether branded or generic. In some parts of Africa, Asia, and Latin America, over 30% of sold drugs are counterfeited [2]. This suggests that some patients are taking drugs that have neither a curative nor a preventive effect on the disease. In view of these problems plaguing the supply chain, the implementation of a drug transaction tracking system is mandatory.

Conventionally, drug transaction tracking has been supported by centralized platforms. For instance, authors of [3], [4] proposed cloud-based tracking platforms for drug traceability in the USA, that are consistent with the serialization of drugs. The identification of drugs has been provided through a 2D data matrix barcode with a unique product identifier, packaging identifier, batch, expiration date, and other optional metadata. Since this system is cloud-based, all stakeholders or players within the supply chain would connect to the same data source to facilitate drug item authentication before processing it to the next player within the supply chain, until reaching the patient. In [5], the authors proposed to use radio frequency identification (RFID) chips instead of barcodes for item traceability. Similar to the previous ones, the solution is cloud-based, which presents risks of single point of failure and data alteration.

As an alternative, distributed systems have been recently discussed, powered by the development of blockchain technology. Indeed, blockchain is a novel paradigm that is able to guarantee the transparency, immutability, and authenticity of stored data in the ledger. For instance, authors of [6] provided an overview of the different platforms for drug traceability in general developed with different blockchain types, including on-chain ADLT, FarmaTrust, and Waltonchain, and on-chain-off-chain Drug Recall Chain and VeChain. However, most of these approaches rely on the use of RFID or IoT devices within the drugs, which may not be a cost-efficient method and, depending on the method, either private or public blockchain is used. Given that the public blockchain is more cost-effective than the private one, authors of [7], [8] discussed the architecture and benefits of an Ethereum-based drug-tracking system. This idea has been implemented in [9], where the authors leveraged smart contracts and decentralized off-chain storage on InterPlanetary File System (IPFS)

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protocol for efficient drug traceability in the supply chain. Through simulations, they tested and validated the designed system. Also, they evaluated the incurred costs of blockchain-related operations. However, the implemented solution does not lighten the load of blockchain. In fact, the solution focuses on batch management of drugs. This means that each new batch will have its own smart contract, the address of which will be used to identify the boxes of medicines it contains. What's more, almost all storage is blockchain-based: only the images of the batches and boxes are stored on IPFS.

As discussed in the state-of-the-art, the emergence of the blockchain and IPFS have opened new perspectives for drug management. Indeed, these technologies are able to solve critical challenges including data traceability, transparency, counterfeiting, and security between supply chain players. However, large-scale blockchain is still prone to issues such as scalability, interoperability, and high storage costs. Consequently, in this paper, we aim to propose a novel hybrid blockchain-IPFS drug transaction tracking platform that ensures lighter and low-cost data storage at the blockchain, and efficient data recovery from IPFS, while guaranteeing the transparency, integrity, and security of drug data. Unlike the proposed IPFS/blockchain method of [9] where drugs are managed in lots and both drug transactions and involved parties are recorded within the blockchain, we propose here a lighter blockchain usage where only the identification of drug and reference to transactions is within the blockchain.

The remainder of the paper is organized as follows. Section II details the system architecture for the proposed drug-tracking platform and explains its operation. Section III presents the obtained experimental results. Finally, section IV closes the paper.

II. Proposed Hybrid Blockchain-IPFS Drug Tracking Platform: Architecture and Operation

A. System Architecture

We consider the typical national drug supply chain in Senegal, as shown in Fig. 1. The supply chain is composed of many players: 1) the *central store* is the country's national depot and the only structure authorized to introduce drugs into the circuit. Drugs are mainly obtained by tender from foreign suppliers. As soon as they are acquired, the central store registers them before repackaging them into batches for delivery to the primary redistributors, called the *regional pharmacies (PRAs)*. The PRAs are responsible for supplying health *districts* and *hospitals* based on the pre-ordered quantities. *Health posts* and *health centers*, for their part, obtain their supplies from their supervising district, while *health huts* are supplied by the supervising health post. The general *population* can buy prescription drugs from either hospitals, health centers or posts, or health nuts.

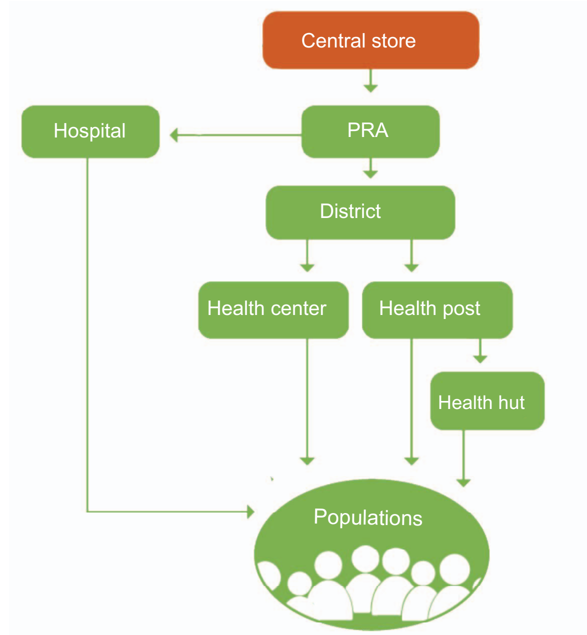

Fig. 1: Drug supply chain in Senegal.

Given the supply chain mechanism explained above, we develop the architecture of our proposed drug tracking platform as illustrated in Fig. 2. The platform is composed of:

1) **Stakeholders:** include the central store, the PRAs, hospitals, districts, health centers, health posts, and health huts. Depending on their level within the supply chain, stakeholders are assigned specific functions. They have access to chain resources, such as history and logging information to track transactions within the supply chain. Moreover, they have access to the decentralized IPFS storage resources for traceability information and drug status updating.
2) **IPFS decentralized storage system:** The IPFS system provides low-cost and secure data storage. It is used to keep drug traceability data in files and guarantee data availability, reliability, and integrity. Data integrity is satisfied through the generation of a unique hash for each data file published on an IPFS server. The hashes of the latest versions of the various files are then stored in the blockchain.
3) **Ethereum smart contracts:** They ensure the supply chain deployment. Specifically, a smart contract is used to track transactions' history and manage the file hashes of decentralized storage in IPFS servers, thus enabling participants to access traceability data. Moreover, adding, retrieving, and updating functions of the drug reference data are

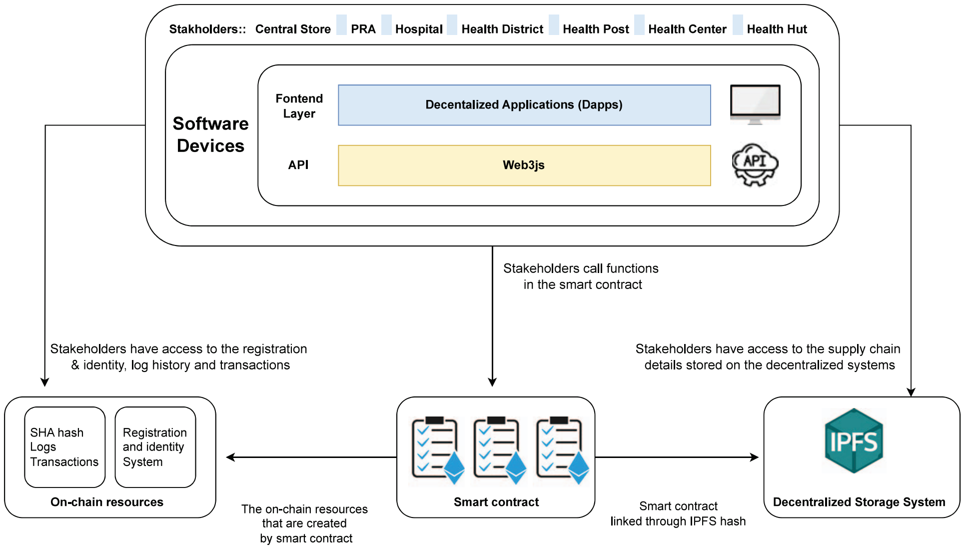

Fig. 2: Architecture of the proposed Blockahin-IPFS drug tracking system.

defined within the smart contracts, and access to them is granted to authorized participants only, using modifiers.

4) **Blockchain resources:** They are used to store log data and events generated by smart contracts, thus allowing data status monitoring and traceability. In addition, a registration and identity verification system is used as an on-chain resource in order to associate the Ethereum addresses of individual participants with human-readable text stored in a decentralized manner.

B. *System Operation*

The proposed solution is developed to allow the following supply chain operations:

1) **Drug registration:** As shown in Fig. 3, drug registration is operated at the central store. First, essential information about the drug is provided, including its name, weight, number of pills, expiration date, original batch that belongs to its stock, etc. To this data, we add the name and address of the storing warehouse and the type of structure involved before storing it all in a JSON file. Then, this file is published in the IPFS infrastructure and constitutes the first version of the drug data file on IPFS, which is accessible from the *hashIPFS* generated by the decentralized storage system. Then, a quick response (QR) code is generated from the file's IPFS hash and stored in the backend (DApp). To guarantee the authenticity and integrity of files stored on IPFS, a reference between the QR code and the file is created. Specifically, the generation of the QR code triggers a transaction to be added to the blockchain. This transaction includes the IPFS hash and the link to the QR code.
2) **Drug history retrieval:** In Fig. 4, we describe the steps to retrieve a drug's traceability data. First, using a mobile application, the QR code labeled on the drug's packaging is scanned. Then, the link related to the QR code is authenticated on the Ethereum blockchain. If authentic, the associated *hashIPFS* is returned. Using the latter, the IPFS decentralized storage system is asked to retrieve the corresponding data file, and then, display its content on the Mobile App.
3) **Drug information update:** We present in Fig. 5 the data update process for a given drug item. This process is triggered only when a drug order is received by an involved party in the supply chain, except for the central store. Indeed, when a party replenishes its stock, it must notify the drug tracking system of each new item in its possession. To do so, it starts with the *drug history retrieval* process. Then, the system creates a new JSON file that contains the history data, to which information about the new holding party/facility of the drug is added. This new file is published on the IPFS system and a new *hashIPFS* is provided. Finally, the updated traceability data is reflected on the blockchain by updating the drug references on the blockchain, i.e., replacing the previous *hashIPFS* associated with the QR code link with the newly generated one.

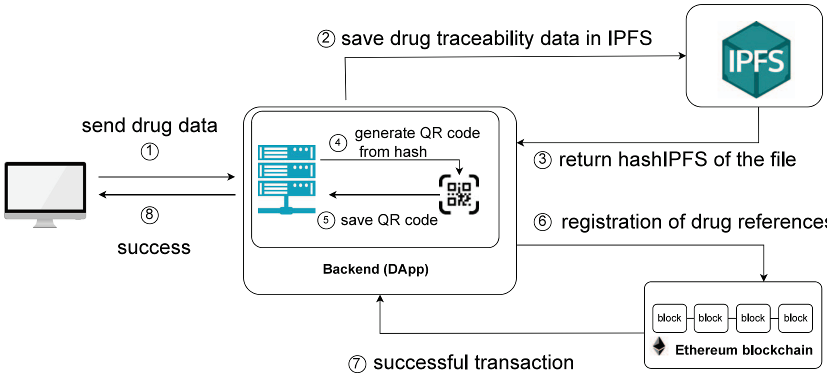

Fig. 3: Drug registration process.

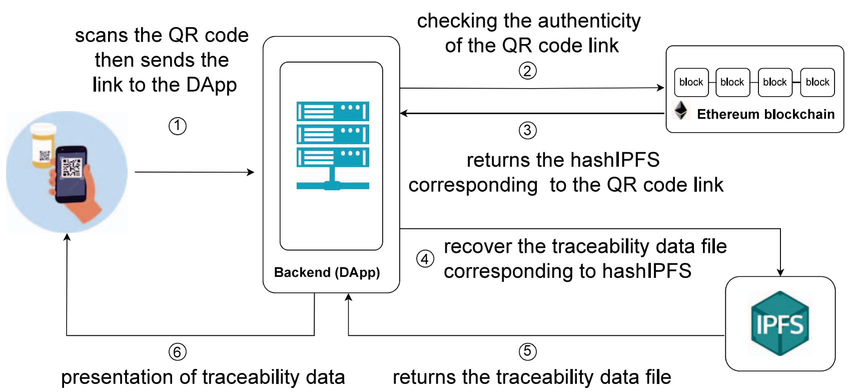

Fig. 4: Drug history retrieval process.

III. Deployment and Evaluation of the Proposed Drug Tracking System

The proposed solution is implemented using IPFS and the Ethereum blockchain. The smart contract, written in *Solidity* programming language [10], is tested and then deployed using the *Truffle* development framework [11]. The contract is deployed and tested locally using *Ganache* Ethereum blockchain [12].

In Fig. 6, we illustrate the relationship between the *drug smart contract* and the *IPFS system*. The smart contract deployment includes attributes such as the *data structure drug* composed of *qrcodeURL* corresponding to the link to the QR code, and *hashIPFS* representing the address of the latest version of the associated file on the IPFS system. In addition, we define a mapping between *listDrug* and *Owner* to characterize the address of the contract's owner. Whenever a transaction is carried out on the system, it is announced to all participants. Moreover, the smart contract has three methods to ensure that the tracking process runs smoothly: 1) *addRefDrug* to create drug references, 2) *getRefDrug* to retrieve drug references, and 3) *updateRefDrug* to update the drug references. A demo for the execution of the aforementioned operations within the proposed hybrid drug tracking platform can be found on Youtube [13].

In what follows, we evaluate the performances of our proposed hybrid blockchain-IPFS platform, in terms of process and storage costs. Then, we compare them to those of the full blockchain platform.

For the proposed solution, data is stored on the IPFS system. We assume here that we use the IPFS service

TABLE I: Costs for blockchain-based drug transaction tracking system.

Process	Used gas	Cost in Gwei	Avg. cost in USD
Deployment (Blockchain)	4 078 722	10 196 805	19.955
addRefDrug	294 348.95	735 872.37	1.440
updateRefDrug	148 353.59	370 883.975	0.725

TABLE II: Costs for proposed drug transaction tracking system.

Process	Used gas	Cost in Gwei	Avg. cost in USD
Deployment (Blockchain+IPFS)	704 961	1 762 402.5	3.449
addRefDrug	165 316	413 290	0.868
updateRefDrug	51 452	128 630	0.311

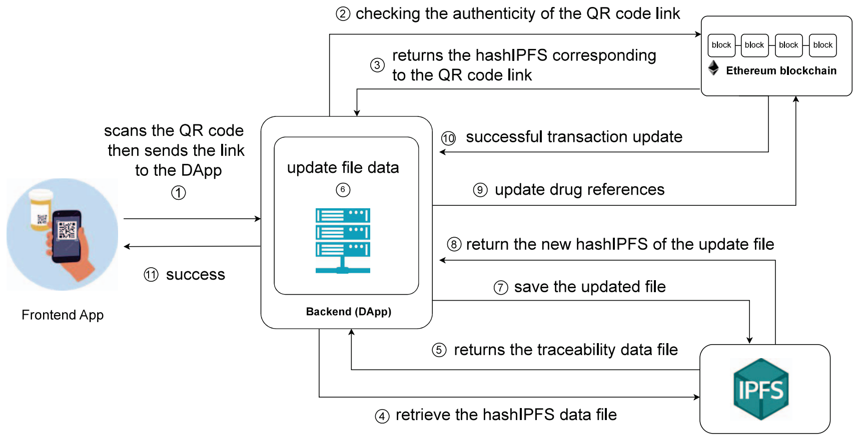

Fig. 5: Drug information updating process.

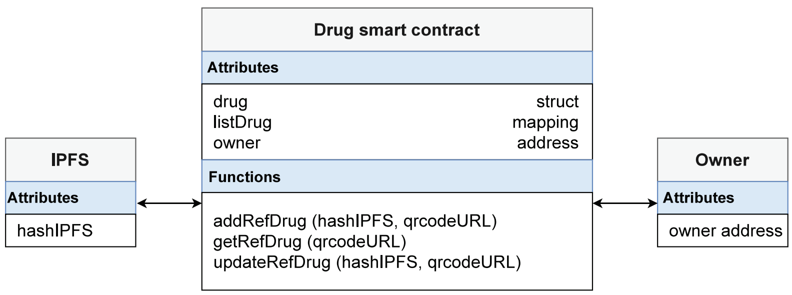

Fig. 6: Entities Relationship Diagram.

of *Pinata* with *Picnic* subscription, which offers the registration of 20,000 files at the monthly cost of \$20 USD. When the blockchain is used, the cost in terms of Gas, Gwei and USD is provided by the *Ganache* system. For a transaction to occur, an amount of *Gas* is required, which costs *Gwei*. *Gas* fees are payments in ether (ETH) made by users to compensate the miners and validators for the consumed computing energy required to process and validate transactions on the blockchain. *Gwei* is evaluated as 10^{-9} ETH, while the cost in USD depends on the ETH market's price. Here, we used 1 ETH= 1957.01 USD as consulted on November, 16th, 2023 at 4:53 pm EDT [14]. Typically, medical data need to be stored between 5 and 10 years. We consider here a period of 5 years, meaning that to store an IPFS file for 5 years, a cost of $20/20000 * 12 * 5 = 0.06$ USD is incurred.

For comparison between the blockchain-based and proposed solutions, we consider the following scenario: Smart contract is deployed and the structures making the longest circuits within the supply chain, i.e., drugs that go through *Central store→PRA→District→Health post→Health hut→Population*, are recorded. We assume that 23 different drugs are registered and start transiting through the supply chain. Their corresponding transactions are recorded within the blockchain or IPFS (depending on the approach), for which we collect the size of the data recorded and the cost of processing the transactions.

Tables I and II present the average transaction costs of the processes implemented for drug tracking in the blockchain-based and proposed frameworks, respectively. Costs are expressed in gas, Gwei, and USD. The average gas price used here is 2.5 Gwei.

Accordingly, we notice that the average transaction (or smart contract) deployment cost for the blockchain-based system represents approximately 579% of the deployment cost for the proposed solution. Also, our approach reduces the drug registration and drug information update costs by 39% and 57%, respectively. Indeed, the use of the cheaper IPFS storage option and the reduction of the size of data needed within the blockchain significantly contribute to this gain.

Given the same deployment scenario as previously, we present in Fig. 7 the size of data stored (within IPFS or blockchain) as a function of the number of transactions generated to follow the supply chain circuit of the considered drugs. For the tracked transactions, the size of data for the blockchain-based system is higher than that of the proposed hybrid solution. This difference is due to the high storage space occupied for the deployment of the smart contract and the addition of

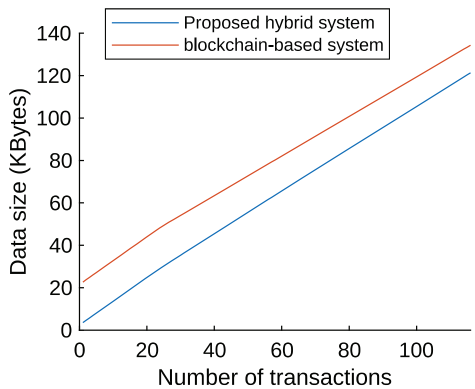

Fig. 7: Stored data size vs. number of transactions.

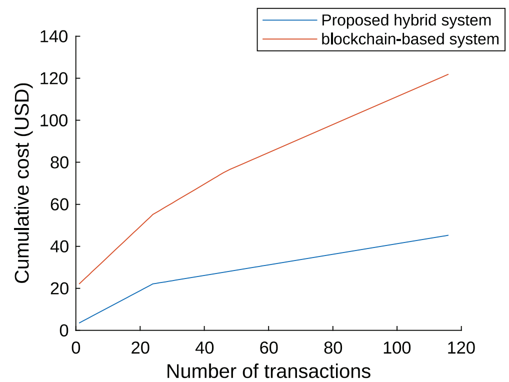

Fig. 8: Cost in USD vs. number of transactions.

structures in the blockchain-based system, evaluated at 22.66 kilobytes (KBytes) before generating any transaction, compared to 3.55 KBytes for the proposed system. However, we notice that as the number of transactions increases, the gain of the proposed system shrinks and after hundreds or thousands of transactions, the trend would change, in which the proposed solution stores more data per transaction than the blockchain-based system. This situation may be due to the fact that new updates within the blockchain add only new information, e.g., information about the new party who acquired the drug while using the IPFS system requires that the novel recording includes both old and new data.

Although the IPFS data size would exceed that of the blockchain through time as discussed in Fig. 7, surprisingly, the cost of storage within the distributed IPFS system is significantly lower than for the blockchain-based system. With the increase in the number of transactions, the cost gap between the proposed hybrid system and the blockchain-based one increases even further. This is due to the expensive operations needed within the blockchain to store new data compared to IPFS. Hence, this result validates the choice of IPFS as an economical and affordable solution for drug transaction tracking systems.

IV. Conclusion

Given the criticality of drug transaction tracking and product traceability to ensure protection against counterfeit drugs, especially in underdeveloped countries, we propose in this paper a novel solution based on a hybrid blockchain-IPFS framework. The idea behind it is to provide efficient drug history traceability in the most cost-effective manner. We developed the proposed framework. Then through experimentation, we deployed it, proved its smooth operation, and evaluated its processing and storage costs compared to the fully blockchain-based framework. In addition to exceeding the security standards of the conventional blockchain, thanks to its usage of encrypted IPFS storage, our method reduces costs by up to 82%. Our approach provides important guidelines to design cost-effective product transaction tracking systems, needed especially in underdeveloped countries to fight against counterfeit items and corruption.

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