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Increasing Supply Chain Efficiency Using Blockchain Technology

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ABSTRACT :

Nowadays, the issue of counterfeiting in the pharmaceutical industry is one of the main challenges facing many countries. maybe due to the lack of effective methods of tracking the product through the different stages of the supply chain and the lack of concurrent observations between all parties involved in the system about the current status of the product. The research purposes a framework that integrates the blockchain technology with Internet of Things (IoT) based technology. Pharmacy supply chain management system can provide greater security. We look at peer-reviewed blockchain technologies against two criteria for supply chains: on-chain storage and off-chain storage. Therefore, we used the Inter Planetary File System (IPFS) to achieve tamper-proof storage to avoid unauthorized modifications. Thus, we have achieved a great degree of transparency and trust in the supply chain. Improving the methods of controlling the storage, shipping, and distribution, through the constant storage of product status changes that are shared across all parties enables verification of product authenticity across various parties in the supply chain to leverage the blockchain.

Keywords *Drugs Supply Chain, Blockchain, Drugs Grey Market, Drugs Manufacturing Industry, IPFS Protocol, Supply Chain Management (SCM), Internet of Things (IoT).*

1. INTRODUCTION

Recent coronavirus spread in the last few months is considered one of the challenges which forced us to re-engineer many things, think about how to benefit from technologies which are used to encounter this pandemic. However, scientific research until now still lacks the appropriate medicine to face this virus. As a matter of fact, many countries especially developing countries are facing a crisis in providing some medicines so there are increasing opportunities for counterfeit substandard drugs to enter the supply chain (SC) and be delivered to patients as genuine products. Despite the complexity of the current pharmaceutical supply chain, there has been an increased opportunity for counterfeit and non-standard drugs to enter the legitimate supply chain and deliver them to patients as original products, This can be the result of the failure to have a suitable application as well, it is almost impossible to discover that the drugs are 100% safe or disclose their origin. Because of the use of paper pathways and ineffective techniques, as well as the expansion of the use of the supply chain in its traditional form and dealing with a large number of suppliers, tracking medicines across all stages of the supply chain becomes very difficult. This has become a major health concern for patients worldwide, even in developed countries. Various solutions have been proposed to improve security and transparency in the entire supply chain such as providing new ways to track products such as Radio Frequency Identification (RFID) and reviewing product transfer terms while integrating some modern technologies such as the IoT to monitor the status of shipments. However, after resolving some

major problems, these applications still do not add a fully reliable supply chain of pharmaceutical products to prevent counterfeit medicines and meet end-user expectations of product quality.

However, all of these solutions that address key issues do not ensure drug safety, prevent counterfeiting and meet the final product quality requirements. Certain supply chains use such methods of reliable data collection by means of information sharing tools such as bar codes and RFID, which facilitate data acquisition and improved traceability in the medical supply chains. The new medical supply chain management procedures, struggle to a large extent from data instability and central controls, proves the ability to be tampered with and manage data because it is based only on the Internet of Things. When it comes to issues related to counterfeit medicines in the drug supply chain, we find that the combination of IoT based blockchain technology and the supply chain is the best solution to this problem. Blockchain technology stands out as a way to ensure that the ledger chain transactions are unchanged, and to monitor every stage of the supply chain at the product level. So, we have already incorporated IoT based blockchain technology and IoT based supply chain into a framework that aims to:

- use blockchain in traceability and transparency to detect and combat fraud in the drug industry using IoT capabilities.
- use RFID tags and QR Code to track products and to ensure the content of the shipment along the supply chain and store the collected data as a transaction on a blockchain.
- Strengthen security for IoT capabilities using distributed ledger technologies and smart contracts to keep data and communications confidential.

2. PHARMACEUTICAL SUPPLY CHAIN CHALLENGES AND OPPORTUNITIES:

- ***Damaged product*:**
  Pharmaceuticals safety precautions and quality control require more attention than most consumer products, because pharmaceuticals are most susceptible to damage during transportation.

- ***Transparency:***
  Existing supply chain management systems lack transparency and immediate end-to-end data access. It leads to distrust and inability to take corrective action in a timely manner, this leads to loss of drug efficacy and possibly to the patient's life.

3. AIM OF THE WORK

The main research objective is how to use Blockchain technology to improve the efficiency of the pharmaceutical supply chain:

- Track medicines from beginning to end and create a reliable and secure database
- To enhance transparency in the supply chain Anti-counterfeiting, because the Blockchain only allows trusted people to change data.
- Preventing medications from being damaged during transport and storage, as the IoT system provides alerts to network partners if there is any risk to the medication.
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4. METHODOLOGY

We aim to enhance pharmaceutical Supply Chain Management (SCM) as previously mentioned. So, data integrity, dependability and authenticity of the related information have big consequences on the final product quality and safety. But, Scalability is a significant challenge after confidentiality. Suppose a network throughput of 500 transactions per second for decent blockchain system. If the objective of the chain is to store records, then the size of each transaction depends primarily on the amount of information which holds it. Also, to store the return address, digital signature, and any other bits, each transaction may require 100 bytes of overhead. If we take a test case of a small JSON architecture of 100 bytes for each element, then the total data throughput will be 100 kb/s, measured by 500 x (100 + 100). This is represented by a bandwidth of less than 1 Mbit / s, which is handy within the ability of any current internet network. It would collect data at a rate of about 3 terabytes a year, which is not a small size. Accordingly, we conclude that direct storage on the blockchain is not an appropriate and practical option for blockchain applications integrated with the Internet of Things that store a lot of big data. There is also a crucial question, how do we provide original content outside the blockchain (off-chain) to the parties to the supply chain that need them?

So, we decided to use the IPFS protocol, which realizes the decentralized delivery of off-chain content. It fits with the blockchain decentralization methodology. This protocol relies on a "content-addressing" mechanism, as the hash is automatically generated after storing the content inside the IPFS, and acts as an identifier to retrieve that data. Each participant in the supply chain will manage both the blockchain node and the IPFS node. The original data will be stored in IPFS and then a transaction will be created on blockchain containing a hash of this data, this hash is used later to retrieve the original content stored in IPFS.

Finally, to prevent unauthorized changes, the IPFS node automatically verifies the obtained content vs. the hash.

5. CONTRIBUTION

This paper contributes to addressing challenges by combining the Internet of Things and Blockchain to improve supply chain efficiency. The supply chain is a relatively complex process and can contain dozens of steps from purchasing raw materials to ship finished goods. These steps are the strength point in the Blockchain because the more nodes in the network, the more safety and transparency, and no messing around. Blockchain technology is a promising technology with many advantages that can develop transparent supply chain management leading to safe and anti-counterfeit pharmaceutical manufacturing industry-leading to customer confidence and satisfaction. Blockchain with the Internet of Things can transform supply chains. Blockchain is a great start for the supply chain industry. It consists of global architectural and management decentralization because there is no infrastructure central point of failure and management. However, despite its feature in terms of security, safety, and transparency, it cannot handle large amounts of data which is involved with the supply chain so is a major problem. It is also a very affordable way to store the large data produced by IoT devices. We suggest the use of IPFS for the efficient storage of data and digital content.

6. BACKGROUND

a. Blockchain Technology: An Overview

Blockchain is a technology that is based on distributed ledger technology, where every participant has a copy of all data stored in the network, eliminating centralized control of data flow. The data is added to this ledger with the consent of all participants that agree on certain conditions to validate this data before adding it to the ledger. Thus, preventing manipulation of data and trying to tamper with data after adding it to the ledger. Blockchain has the potentials of immutability and decentralization. Although Blockchain is an efficient way to store data, it is costly in the case of big data and big content, so we suggested using IPFS.

b. Internet of Things (IoT)

IoT is a system of interrelated computing devices, mechanical and digital machines provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. [1]

c. Interplanetary File System (IPFS)

The Interplanetary File System is a protocol and distributed file system to store data in a peer-to-peer network. IPFS uses content-addressing to uniquely identify each file in a global namespace connecting all computing devices. [2]. With IPFS, we can address large amounts of data and put immutable, permanent links in transactions — times tamping and securing content without having to put the data itself on-chain.

d. Smart Contracts

Smart contracts are computer code that simplifies the implementation of certain agreements and reduces the need for a middleman. Smart contracts and blockchain are two interrelated technologies, whereby the blockchain constitutes an application platform for smart contracts, or in other words, smart contracts are applied to the blockchain. Smart contracts allow the blockchain to create trustworthy protocols. This means that both parties can make commitments via the blockchain without needing to know or trust each other. They can make sure that if the conditions are not met, the contract will not be executed.

Benefits of combining Blockchain and IoT technologies in drug supply chains with IPFS

At the moment, the combination of Blockchain with IoT dominates a lot of sectors, so this combination is very important. Blockchain data is tamper-proof; thanks to its cryptography and time stamping techniques that prevents any manipulation to its data. Thus, integrating Blockchain with the IoT-Supply Chain Ecosystem may provide more reliable means of drug

tracing, fraud detection and overall product safety across supply chain phases. The concept of smart contracts, a self-triggered program that exists on the Blockchain network, powered by Ethereum Virtual Machine (EVM) can be utilized to handle temperature control or location traceability and event-driven situations in an IoT environment. However, despite the many advantages that come with integrating Blockchain with IoT in the supply chain, it cannot handle large amounts of data produced by IoT sensors, so this is a problem. It is also an expensive way to store data, especially for big data and digital content. So, we suggest the use of IPFS for the efficient storage of broad data and content. Combined with event logging on the Ethereum blockchain, we use a private network of IPFS digital information storage nodes to guarantee that shippers, distributors, and end consumers can reliably recover shipping records, and to guarantee that records of drugs used in shipping transactions are verified and tamper-free shipment. While all metadata is uploaded to IPFS, there's no central data clearinghouse containing (or possibly vulnerable) confidential shipment records, like financial information or other publicly identifying information. The implementation of our proposed solution utilizes both Ethereum smart contracts and IPFS, whereby the information belonging to the shipment is uploaded to the IPFS and the IPFS hashes are stored to provide traceability and authentication in the Ethereum smart contracts. The hash returned from IPFS can, in particular, be easily preserved in smart contracts and records can be read with the hash [3]. When the quality of the digital record shifts, the hash adjusts to indicate that the initial quality has been changed and tampered with. The downside to using such off-chain storage is that the smart contracts do not directly access the data, making automating operations on the blockchain more difficult. The figure 1 illustrates the link between smart contracts and IPFS.

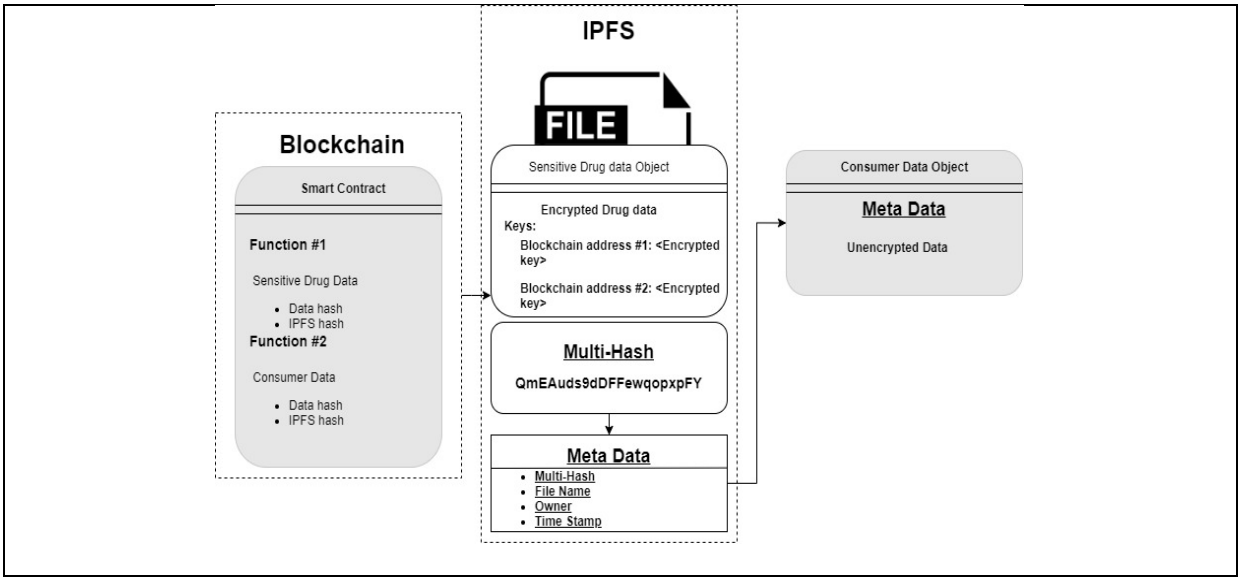


Fig (1) illustrates the link between smart contracts and IPFS

Benefits of using blockchain with IPFS:

- **A unique fingerprint** (cryptographic hash) is provided for each file and all the blocks inside it.
- **No Replication:** Cannot duplicate files of the same content and only store once.
- **Data integrity**: because IPFS uses content-addressing which give each file uniquely identify called hashes.
- **Content-addressing**: is a unique identity for content of data stored which is the data's hash.
- **Tamper-Proof**: IPFS would realize that the information has been tampered with, if the hash is changed.
- **Middleman-free infrastructure** that requires various parties without a central data broker to view official records.
- Ability to store records without having to rely on a centralized cloud storage network, even in perpetuity.
- Option of operating as a private network without losing performance.
- Ease of adoption with the blockchain Ethereum.

Table 1. Supply Chain actors, current limitations faced and blockchain impact.

Supply chain actor	Current limitations	Blockchain impact
Manufacturer	Limited ability to monitor the product to the final destination. Limited capabilities of checking quality measured from raw material	Added value from shared information system with raw material suppliers and distribution networks.
Distributor	Custom tracking systems with poor collaboration capabilities. Limited certification ability and trust	Ability to have proof-of-location and conditions certifications registered in the ledger.
Retailer	Lack of trust and certification of the products' path.	Track of each individual product between the end consumer and the wholesaler. Ability to handle effectively return of malfunctioning products.
End user /Consumer	Lack of trust regarding the compliance of the product with respect to origin, quality and compliance of the product to the specified standards and origin	Full and transparent view on the product origin and its whole journey from raw material to final, purchased product.

Source: https://www.mdpi.com/2305-6290/3/1/5/htm# [4]

7. RELATED WORK

- Randhir Kumar et al. [5] provide drug safety using Blockchain and encrypted QR code security, and authenticate Supply Chain Participants Identity Based on PKI (public key infrastructure) and Blockchain digital signature.
- Thomas Bocek et al .[6] used the Internet objects and the mass of the Blockchain in the stages of operation of the supply chain in the product stages in reducing Supply Chain operational cost, enhancing drugs data immutability and monitoring transportation phase of drug supply chain using Ethereum Virtual Machine (EVM) to handle smart contracts and developing an IoT & Blockchain Hybrid Ecosystem.
- Feng Tian [7] motivated by the great interest in many companies in the problem of food safety and control, focused on the use of modern techniques in the control and tracking of food systems, depending on the so-called supply chains to follow food and analysis of the risks resulting from the study was based on the modern technologies represented. Block Chain and the Internet of things are used to provide an information platform for the members of the chain and achieve a kind of transparency among the members of the series and ended the study to present the most important challenges facing these modern technologies in the food industry.
- Walid Al-Saqafa, et al [8] focused on the aspects of using Blockchain technology and potential applications in many different problems in the business environment of the society and the prospects of their applications in some important industries and how to benefit from them.
- Krystsina Sadouskaya, [9], focused on an analysis of innovative "Blockchain" technology and the potential of Blockchain-based applications. The main goals were to determine how Blockchain could change the supply chain and logistics industry. Typical challenges in these areas have been considered and key features of the Blockchain that can solve these difficulties have been flagged. In connection with this effort, the head of IoT business development at Kouvola Innovation Ltd. was interviewed to see the real challenges or benefits of Blockchain-based applications.
- Ijazul Haqet al. [10] provided a system for tracking medications from their manufacture to delivery to the patient. The effect of the medicines on the patient will be recorded after their use in a database of future statistics. By using authorized Blockchain to store transactions, only trusted parties will be allowed to join the network and push data to the Blockchain ledger.

8. PROPOSED FRAMEWORK:

Our proposed framework aims to enhance pharmaceutical supply chain management in these four main areas: Drug Traceability, Supply Chain Transparency, Security and Compliance & Trustworthy of Supply Chain Management(SCM) using

Blockchain. As we believe these are the main drawbacks of the current supply chain management methodologies that Blockchain could contribute in providing a more reliable solution for them resulting in a more efficient supply chain management system.

a. Drug Traceability and Safety

Ideally, the main objective for drugs supply chain is to ensure delivery of proper medicine for the end-consumer (in this case, the patient) in orders to help cure him efficiently. But in the real world, this is not always the case. Despite the regulations around drug manufacturing industry, there are many drugs out there that are counterfeited. Many recent solutions suggested the integration of Internet of Things (IoT) technology to replace old traceability techniques. However, IoT ecosystem is believed to have many security problems when it comes to protecting user's data integrity and availability. The Blockchain, however, is a decentralized peer-to-peer network that doesn't depend on a centralized entity to control the data flow in the system. Also, the data is stored in distributed ledger between all participants. Blockchain data is tamper-proof thanks to its cryptography and time stamping techniques that prevents any manipulation to its data. Thus, integrating Blockchain with the IoT-Supply Chain Ecosystem may provide more reliable means of drug tracing, fraud detection and overall product safety across supply chain phases.

b. Supply Chain Transparency

Nowadays, Supply chain scalability has increased way more than before as shown in Fig-3., resulting in a confusion of a huge number of suppliers. Despite the benefits of this, it has become more difficult to give accountability for actions performed in the supply chain and detect anonymous participation (to detect source of counterfeit, for example). With Blockchain there is eliable identity management in the system, therefore, parties in the network could simply know which participant is performing what action, when and even where. This could improve supply chain's accountability as each entity knows his identity and actions are not hidden and could be hold accountable.

c. Security

It's now clear to everyone that supply chain networks need to radically improve security, so, supply chains must become more secure and transparent. Providing Blockchain as a peer-to-peer network, it is immune to many cyberattacks that could threaten the standard centralized architecture of the supply chain. Thus eliminating the weakness of a single-point-of-failure entity in the system. Also, Blockchain's data log is immutable, which means Blockchain records cannot be modified once it was added in a block to the chain. If it is meant to change the data in one specific block, all previous blocks must be modified in order for the change to occur. This could improve supply chains maintainability of transactions and business activities logs instead of relying on centralized databases.

d. Compliance & Trustworthy

As we mentioned earlier, Blockchain's time stamping techniques and distributed peer-to-peer ledger interaction between all participants, and its identity management methodologies allowing collecting time, location and many other data about a specific event that happened. in the system. With that collected data being tamper-proof, and with handling business logic with smart contracts - a self-triggering program running onto the Blockchain - all of this adds up to the trust of the end-consumers in the system, and creates a trusted environment between different entities in the drugs supply chain where untrusted parties can

Fig (2) – Blockchain and IoT integration impact on Supply chain

be easily detected and forfeited.

9. PROPOSED SOLUTION

In this paper, we suggest a blockchain-based approach integrated with IPFS to address the validity and authenticity of the drug supply chain. Here, we illustrate how this issue in the supply chain can be addressed for shipping and demonstrate how our system is capable of tracing and monitoring the digital content of the shipment, back to the actual licensed product made by the original manufacturer. Since the inception of the term smart contracts in the mid-1990s with the Ethereum platform, they have had a keen interest in the job market. So, in our solution, we highlighted the use of smart contracts and try to enhance scalability and off-chain storage with their efficiency and blockchain compliant limitations byusing IPFS. We need IPFS in our solution to store digital consignment content which includes product manufacturer data and shipping data itself like Drug-ID1, Drug-ID2 etc. In a decentralized, distributed manner, reliant on a "content-addressing" mechanism, and which realizes the decentralized delivery of off-chain content. Which enable us later to retrieve the original content stored in IPFS. The smart Ethereum blockchain contract makes use of this IPFS hash to ensure integrity, authenticity and validity. The IPFS hash value remains the same if the content of the shipment remains unchanged. If the content is tampered with during the supply chain phases, the IPFS hash for this shipment is changed, and then the hash contained inside the smart contract does not match that. Thus, each participant will monitor and verify the authenticity, location and history of the product information stored in IPFS and ensure that the product obtained is legitimate for the manufacturer

a. System Architecture and Design

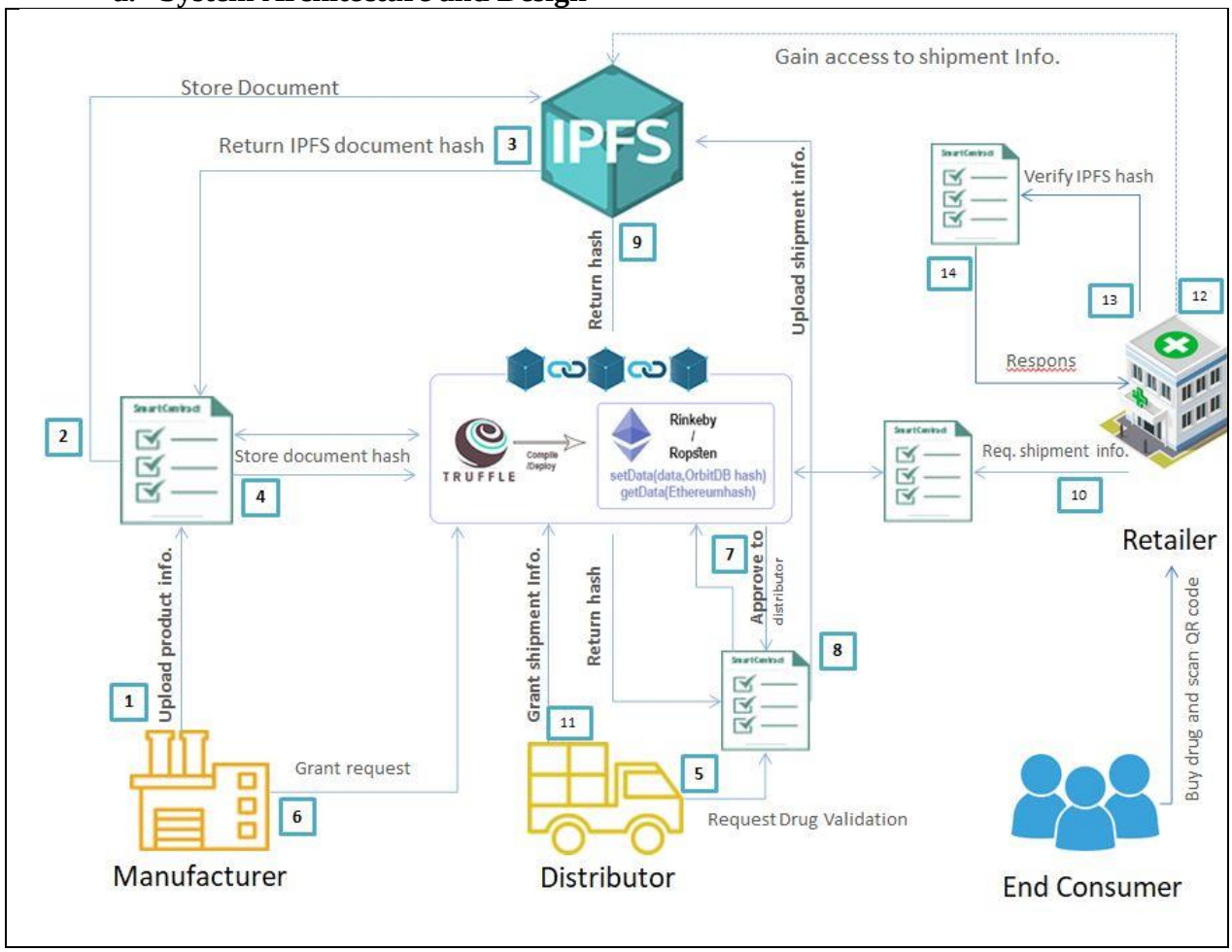


Fig. 3. An overview of the system architecture for Pharmaceutical Supply chain authenticity using IPFS and Ethereum smart contracts.

- **Manufacturer**: is the participant of the supply chain or node in a blockchain that owns the original drug product and digital content of the shipment (QR-code). The Manufacturer creates a smart contract and also maintains the original hash of the shipment. and provides permission for one or more distributors to deliver his shipment. The distributor uploads the digital content of drug shipment on IPFS, only if the manufacturer's notarization is completed.

- **Distributer** : is the entity that obtains permission from the manufacturer to deliver the shipment content in various sources such as pharmacy, hospital, or any end consumer.
- IPFS provides us with maintaining the shipment content as presented by the manufacturer, it also helps the distributor to obtain the proof of site certificates and the conditions recorded in the ledger, and then the distributor uploads the shipment data to files in IPFS. IPFS provides us with maintaining the shipment content as presented by the manufacturer, it also helps the distributor to obtain the proof of site certificates and the conditions recorded in the ledger, and then the distributor uploads the shipment data (QR-code) to files in an IPFS. Instantly, a hash of that data is generated automatically and then stored in the smart contract for later validation and verification by the manufacturer.

- **End consumers or Retailers:**To check the originality of the shipment, IPFS offers trace back functionality through IPFS hash to the end consumers. In consideration of the originality, quality, and credibility of the shipment, retailers can access the history of notarization.

b. Defining the Scenario

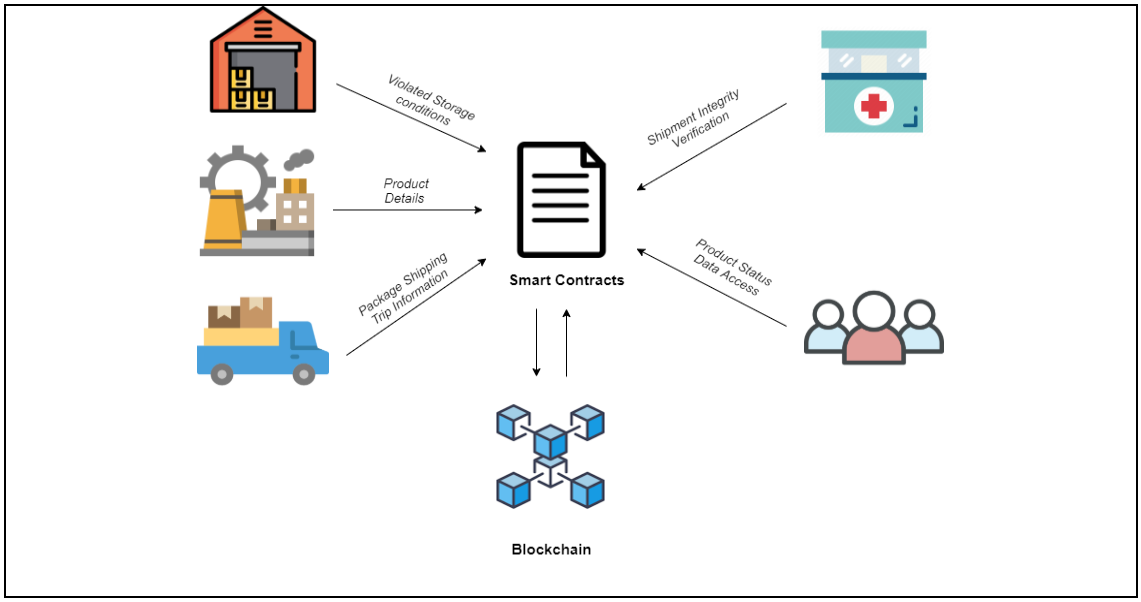
The proposed framework in this research reflects our presentation to solve the research problem by first dealing with a possible real-life scenario. It focuses on using the Internet of Things and Blockchain technology to improve the pharmaceutical supply chain management. This technology relies on the use of speed-sensitive sensors and electronic chips that make it increasingly portable. Many companies are taking advantage of this development and giving them the opportunity to connect sensors with tangible products to track their discoveries of potential failures and scams. We integrate these massively data-collecting sensors with a chain of block that provide standardization, transparency and the possibility of them occurring using a "closed" smart device to authenticate goods that receive confidence along the supply chain. These electronic seals uniquely identify the object to which they are attached and detect or break simply trying to tamper with the body. Attaching the electronic seal to the package of the commodity is a viable solution for reliably tracking and monitoring the item in the supply chain using a RFID with drug shipment. Any attempt to replace it would destroy the seals or make the same good, making it unsold. Sensors and IDs can be used to capture the blockchain as an authentication transaction. We can scan QR code using the appropriate technology and determine immediately to determine whether the product is free of any tampering or fraud.Figure 4 illustrate us a medical safety framework using Blockchain technology, which produces for us a channel for drug safety in the supply chain between the various participants in the chain such as the manufacturer, distributor, patient, hospital and smart contract organization.

All transaction data includes the manufacturer and its product, for example, the ID1 manufacturer manufactures the drug - ID1. This information is understood and circulated to all members of the medical chain's system. This structure here shows transparency among the participants.

The following steps are involved in drug safety

- Under the proposed framework, pharmaceutical companies will produce drugs with specifics such as medication name, venue, timestamp, ingredients, drug usage, and side effects and get them accepted through a regulatory-approved smart contract. The producer produces an encrypted QR (quick response) code for the information and adds it to the blockchain framework.
- Unauthorized users cannot access the blockchain; only legal users may use the public key to access the blockchain.

Fig (4) – The Underlying Blockchain Logic of the Proposed Framework



c. Implementation of the Solution

To implement our solution, we have chosen to use a framework called "truffle" this a world-class development environment, testing framework and asset pipeline for blockchains using the Ethereum Virtual Machine (EVM). It enables us to Buil smart contracts. We have chosen to work with the Go Ethereum (Geth) client, along with Solidity language for smart contracts programming. The Ethereum protocol specifies an interface allowing people to interact with smart contracts and each other over a network. We use the web3.js library to communicate with Ethereum nodes and smart contracts in the EVM with an HTTP link to access up-to-date details regarding contract status, and new transactions. A smart contract is a program that runs within a blockchain. It contains a set of rules that constitute an agreement made between two or more parties. When these rules are met, the digital contract executes the transaction. With IPFS, we can address vast volumes of data and put immutable, permanent links in transactions, time stamping and protecting content, without putting the data itself on-chain.

The system produces two components when the contract is deployed: the bytecode to run on EVM and the Application Binary **I**nterface (ABI). Bytecode runs whenever a function is called from the application and stored into Ethereum blockchain under contract address. ABI defines the structures and functions that can be invoked explicitly. In other words, ABI grants access to call functions in smart contracts. To sum up, three requirements should be satisfied to interact with a smart contract:

1) Bytecode must be deployed to blockchain
2) Address of bytecode must be known
3) ABI of smart contract must be known.

In summary, we can implement the solution as follows:

- Design concept of an end-to-end embedded system
- Basic principles of blockchain and decentralized storage technologies
- Creating transactions on Ethereum network
- Writing smart contract and designing **D**ecentralized **A**utonomous **App**lication (DApp)
- Communicating with smart contracts by using web3 library of Node.js
- Pushing IoT device data into the IPFS and storing reference to the file in smart contract.

10. CONCLUSION

In this paper, we have proposed a solution to the current problems facing pharmaceutical supply chains, such as insecurity and the increasing rate of counterfeit f/medicines, which will certainly affect the lives of many people around the world who are fighting their diseases, as well as the financial aspect of many members of the supply chain. We have tried to highlight how technology like Blockchain can transform the existing drug supply chain to be more reliable and counterfeit-free by enhancing various supply chain management methodologies such as traceability, identity management, and overall network security. But many challenges block Blockchain recently, such as some productivity and performance concerns being a peer-to-peer network. Also, cultural concerns about

human privacy in the Blockchain world where their identity and actions are shared across the entire network. Nevertheless, Blockchain represents a great opportunity for the supply chain to overcome some of its weaknesses and boost its overall performance. also, we have proposed a solution to solve the originality and product authenticity using IPFS and Ethereum smart contracts.

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