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Pharmaceutical Cold Chain Using Blockchain 3.0

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Abstract--- *The term cold chain or cool chain refers to the process of preserving vaccines at consistent temperatures from the manufacturing place along the supply chain to the point of use. Vaccines need to be stored in the temperature range of 2 – 8° C in order to maintain its potency. If the cold chain is broken even for a shorter period of time, then it could result in impotent drug, product wastage, money wastage, and there will be need for revaccination. Monitoring and managing cold chain is an expensive process. According to Pharmaceutical Commerce's Annual Biopharma Cold Chain Sourcebook, by 2021, the worth of pharma cold chain would be $16.6 billion. Moreover, the U.S survey suggested that 1% to 5% Vaccines is wasted due to break in cold chain and it could cost about $31 million. Cold chain management suffers from various problems such as lack of documentation, lack of continuous monitoring, temperature issues and security issues. The perfect solution that comes to rescue cold chain problem is Blockchain. This paper first discusses about cold chain, its importance and the various problems associated with it. It also sheds limelight on Blockchain technology, its versions and how Blockchain could solve the problems of cold chain. This paper proposes an architectural framework that measures and records temperature of cold chain pharmaceutical products using Blockchain 3.0.*

Keywords--- *Cold Chain, Blockchain, IOTA, Sensors, Tangle.*

I. INTRODUCTION

A. Cold Chain

Pharmaceutical cold chain is a complex process of healthcare industry that involves a series of tasks to be performed in order to ensure the desirable temperature range of the products from manufacture along the supply chain to healthcare facilities. In this process, the optimal temperature range of the vaccines must be monitored at each stakeholder's point. FDA has adopted the temperature range of 2 – 8° C for Pharmaceutical products and is now being accepted for all biological agents. If the temperature of the cold chain is broken or if there is an imbalance in the temperature range, the therapeutic effects of the drugs could be degraded resulting in product wastage, money wastage and an expensive revaccination process. [1]According to World Health Organization (WHO), the complete path of the cold chain is illustrated in Figure 1. The top arrows of the path show how data is recorded, checked, analysed and how the drug is manufactured. The arrows at the bottom shows the path of the vaccines from the point of manufacture to healthcare facilities. The regulatory bodies have published standard operating procedure guidelines for shipping. These procedures should be followed till the product reaches the end-user.

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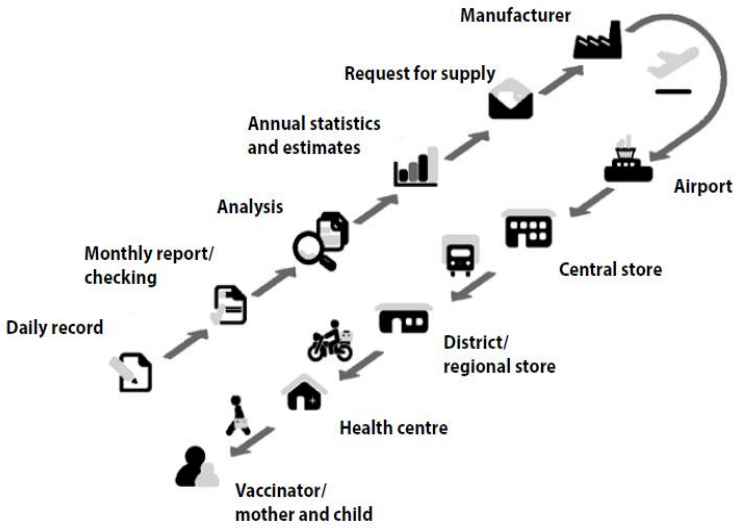

Figure 1: Cold Chain (Source: PATH/WHO)

B. Importance of Pharmaceutical Cold Chain

Cold chain plays the most prominent role in the process of vaccination. Vaccination helps to prevent and control a number of infectious diseases using vaccines which must be maintained in a consistent temperature range known as the 'cold chain'. If the vaccines encounter variations in temperature during its supply, then it's potency could be degraded.

According to a research report by WHO, nearly half of the medicines manufactured by various pharmaceutical companies get lost or contaminated as a result of unsafe temperature conditions of the product during transit or during storage. [2]

Cold chain gains more importance as more and more cell therapies and gene therapies progress worldwide. According to the 9th edition of Pharmaceutical Commerce's BioPharma Cold Chain Sourcebook, the sale of global cold chain and biopharma drugs are set to grow by 31% from 2018 to 2022. The report also says that the overall temperature-controlled Pharma products is growing at twice the rate of the Pharma industry as a whole. Moreover, Logistics spending in the cold chain space is expected to grow from $15 billion in 2018 to over $18.6 billion in 2022. [3]

Cold chain plays an immensely important role in the lifecycle of drugs as the drugs manufactured have high value active ingredients that must be maintained at a strict temperature range failing which the drugs loss its efficacy and potency.

C. Issues in Cold Chain

Following are the various issues and challenges that are associated with the pharmaceutical cold chain:

1. Lack of visibility
2. Monitoring

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3. Security
4. Cost

Lack of Visibility

Visibility of pharmaceutical products becomes more important as the need for temperature control rise. As there is lack of visibility in the current system, Manufacturers, distributors and shippers in the pharma supply chain business risk the loss of temperature sensitive products which could result in loss of billions of dollars. [4]

Monitoring

Temperature monitoring is a key challenge of cold chain management process, as the temperature of the product must be monitored throughout the entire supply chain and also the temperature requirement varies from product to product [5]. Since the pharmaceutical products are high value products, monitoring system should be there to help manufacturers to gain control over their products as it moves along the supply chain.

Security

As the biologics are more expensive and tend to contain high value of active ingredients, they are often being targeted by the thieves and counterfeiters[6]. Counterfeiters could replace the drugs with the counterfeited ones at any stage of the pharmaceutical supply chain. Hence a system that provides security to the products while in transit as well as in warehouse is required.

Cost

Cold chain is an expensive process which needs effective monitoring. Currently, many systems and strategies exist to monitor and record the temperature sensitive products. But, unfortunately, these systems are very fragmented and unregulated and most importantly, very costly. For example, current systems make use of sensors and RFID technologies to monitor and manage the cold chain logistics. But, the cost of RFID system is an important issue which could be around $0.20 and $0.50 depending on its features[7]. Hence, a cost-efficient system to monitor the cold-chain logistics is required.

In a nutshell, a game changer to monitor, to track, to trace and to provide more transparency in the system is required and that could be the Blockchain Technology. By a number of successful projects, Blockchain technology proves that it has the potential to provide visibility, flexibility, compliance, security and reliability of information that is transacted among communicating parties.

II. BLOCKCHAIN

Blockchain, a distributed ledger technology is a growing chain of records without any need for middleman. Blockchain finds its application in numerous disruptive ways and provides immutability, transparency, security, flexibility and governance. Born with the concept of Bitcoin in the year 2009, initially Blockchain was used in the cryptocurrencies field. Spearheaded by Vitalik Buterin, this technology finds its application in numerous other fields such as Healthcare, Education, Public records, Property ownership etc., using the concept of Smart Contracts. Figure 2 shows the structure of Blockchain.

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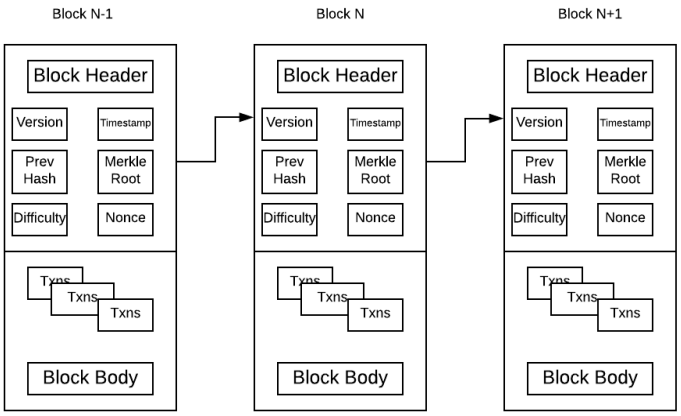

Figure 2: Structure of Blockchain

Each block contains block header and block body. The block header contains metadata about the block such as version, timestamp, previous hash, Merkle root, difficulty and nonce. The block body contains a record of transactions. Each block contains the hash of the previous block through which the blocks are linked and this linking of blocks makes it immutable and tamperproof.

There are three different types of Blockchain.

1. Public Blockchain – It is a permissionless Blockchain in which anyone can join the network at any time.
2. Private Blockchain – It is a permissioned Blockchain in which only the organization that owns the Blockchain can make transactions.
3. Consortium or Federated Blockchain – It is a semi-permissioned Blockchain in which the consortium of members owning the Blockchain can make transactions.

III. BLOCKCHAIN VERSIONS

Figure 3: Blockchain Versions

A. Blockchain 1.0

This version of Blockchain concentrates on cryptocurrencies. It could be used as “cash for the Internet”, a digital payment system. It uses stack-based programming language and Proof-of-Work consensus mechanism. Most popular example of Blockchain 1.0 is Bitcoin.

B. Blockchain 2.0

Overcoming the limitations of version 1.0 such as more resource consuming Proof-of-Work consensus mechanism, stack-based programming language, Vitalik Buterin proposed a version of Blockchain using Turing Complete Programming language that could suit the needs of general-purpose applications.

This version of Blockchain employs smart-contracts. Smart-Contracts are computer programs that execute automatically in which the actual business logic is coded.

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C. Blockchain 3.0

Blockchain versions 1.0 and 2.0 suffers from scalability problem. Blockchain 3.0 tries to resolve this using a new concept called Directed Acyclic Graph (DAG). IOTA, Nano, Byteball and Hashgraphs are examples of Blockchain 3.0. IOTA could be called as a communication protocol for Internet of Things. It enables microtransactions between machines securely based on "Trust in the data" framework. Since IoT devices are lightweight and have less storage space, the founders of IOTA are concentrating on Integration of IoT devices with Blockchain.

Nano is a decentralized digital currency designed to address the issues and inefficiencies associated with the existing cryptocurrencies. It is sustainable, secure, ultra-fast, fee-less and open source network designed to solve peer-to-peer transfer of value.

Hashgraph is a distributed ledger technology that contains *patented* algorithms to provide the benefits of blockchain technology along with scalability. It makes use of Gossip about Gossip and Virtual voting techniques to facilitate micropayments and distributed file storage.

Hence, it is evident that the Blockchain framework ideal for machine to machine transactions is IOTA, which belongs to the family of Blockchain 3.0 could solve the issues associated with cold chain.

IOTA

Since classical Blockchain framework solutions are not suitable for machine economies, a new Blockchain-like protocol that empowers machine-machine transactions is required. The innovation that solves this bottleneck is IOTA, the revolutionary distributed ledger technology designed for IoT devices. IOTA bridges this gap using its distributed ledger called Tangle. Tangle is a Directed Acyclic Graph (DAG) consisting of edges and vertices. Instead of storing groups of transactions as blocks, IOTA contains a stream of transactions that are entangled together [8]

IOTA, the future of Internet of Things (IoT) is the first open source distributed ledger to store data from sensors and data loggers. Powered with feeless microtransactions, security, scalability, data integrity for machine economy, IOTA promises enormous innovation opportunities and efficiency gains in the world of IoT.

Tangle

Tangle is the data structure behind IOTA which differentiates IOTA from other blockchain architectures. Tangle makes use of DAG to represent transactions and approvals. Transactions are represented using Vertices and the approvals are represented by edges. The following figure shows the structure of Tangle.

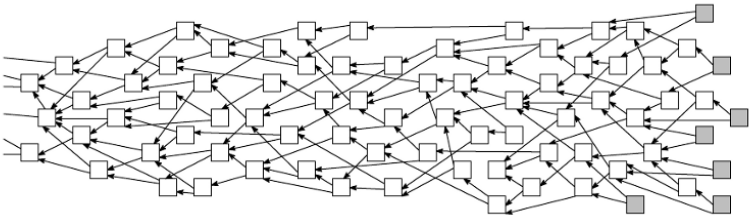

Figure 4: Structure of Tangle

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A new transaction is added as new vertex to the DAG. A new participant can be added to this network, only if he validates two previous transactions by performing small amount of computational work. This makes IOTA to be called as '*pay-it-forward'* system.

Along with transactional value settlements, IOTA is able to store information within Tangle as well as spread large amount of information across multiple linked transactions. The first transaction in the Tangle is called as *genesis* which contains all the IOTA tokens. This genesis gets approved by all the transactions either directly or indirectly.

When a new transaction is added as vertex to the DAG, it is attached to the two previous transactions by means of *approve*.

A transaction becomes immutable, when it is approved by a large number of newer transactions, and the transaction achieves consensus when it has gained enough cumulative weight. The term cumulative weight refers to amount of Proof-of-Work required to validate a particular transaction.

The most prominent feature that distinguishes IOTA from other blockchain is Masked Authenticated Messaging (MAM) which helps IOTA to make cheaper, more secure flow of data and transactions[9]. It also helps sensors and other devices in the network to send their data streams in an encrypted and secure manner[10]. The key features of MAM are post-quantum cryptography and forward transaction linking. These features make the transactions in the IOTA to be quantum-resistant.

Various other features that makes IOTA different from other blockchain are *high scalability, low resource requirement, security, quantum proof, zero-fee transactions and offline transactions.* For businesses and other connected machines, IOTA tangle is able to provide veracity, security and privacy for the data they share.

The Tangle also provides faster throughput by allowing different branches of the DAG to eventually merge, whereas other blockchain has an inherent transaction rate limit.

IV. PROPOSED ARCHITECTURE

In Pharmaceutical Cold chain, the temperature and other attributes of the drugs that are in transit must be monitored and stored to ensure quality, integrity and regulatory compliance. Due to diverse climatic conditions and other factors, it is very complex to accurately monitor and to register the correct temperature values of the products that are moving from source to destination.

Several methods that exist today for measuring and recording temperature values of medicinal products are unregulated and fragmented[11]. A system that could enhance visibility, security and operational efficiency at low cost to ensure vaccine quality is maintained throughout the supply chain is a much-needed prescription for success.

In order to resolve the issues associated with the current cold chain system and their solution, the authors propose an architecture in which the temperature of the pharmaceutical product is continuously monitored using sensors and the result is stored on the Tangle network. The following Figure 5 shows the proposed architecture.

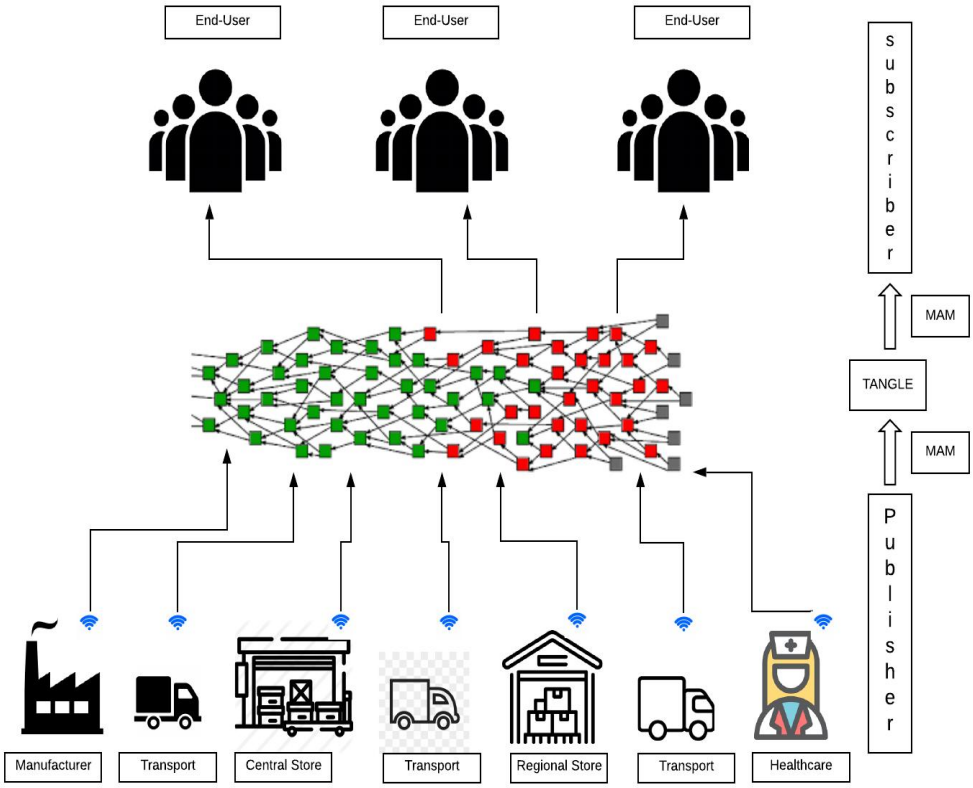

Figure 5: Proposed Architecture

The Proposed architecture consists of manufacturer, central store, regional store, health care, end-users and the transport. Sensors must be attached to the drug packages, immediately as they are manufactured. Smart contracts must be deployed on to the sensors such that they measure the temperature at particular interval and send it to the tangle network. Along with the temperature information, the sensors must be programmed to send the time details at which the temperature of the product is measured. Since the sensors are attached to the drug package, they travel all the way along the supply chain.

The sensor data from each point of the supply chain from manufacturer till it reaches the end-user is broadcasted to the Tangle network. The system makes use of MAM for storing data onto the tangle network and the end-user can retrieve data from the Tangle using MAM. MAM helps to encrypt entire data and anchor them securely on to the network, thus making the data quantum-proof. It also helps the end-users who are authorized parties to decrypt and view the data. Since the data gets stored on the immutable Tangle, it serves as long-term documentation and any one in the network can retrieve temperature data at any time. This brings more transparency and visibility in the system. Through visibility, it is possible to control, manage, review and assure product quality throughout the supply chain process. The sensors could also be programmed to trigger an event that sends message to the manufacturer when the specific temperature requirement of the product is not met. If there is a rise or fall in the temperature range of the products, it could be notified to the manufacturer, so that necessary steps could be taken immediately to maintain the requisite temperature range.

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This helps to ensure product quality as well as save millions of dollars that might otherwise be lost, if the drugs are not maintained at consistent temperature even for a shorter period of time. Further, the data stored on the Tangle cannot be changed by anyone, which makes it suitable for compliance and audit actions.

V. CONCLUSION

It is evident that the cold chain management plays an important role in the supply chain of drugs. Cold chain is a critical process that needs to be monitored and managed to save billions of dollars and lives of many people. The architecture proposed in this paper uses sensors to monitor the temperature and store them on the tangle network. The proposed architecture proves to be feasible, since it needs no fees to make transaction on the network and to store data on the Tangle. The use of MAM for storing and retrieving the data promises authenticity and confidentiality of data. In addition, the system provides supply chain visibility which in turn provides the power and control to manage, review and assure product quality without any interference of third-parties.

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