Towards the Development of a Performance Evaluation of a Hyperledger Fabric Blockchain-based Application for Traceability of Distribution and Recall Transactions in Pharmaceutical Supply Chain

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Abstract

Blockchain technology is a disruptive technology that is currently being adapted for many enterprise use cases and as the applications of blockchain technology continues to widen, the pharmaceutical industry remains an optimistic industry with various challenges to provide solutions for. In this literature review, the researchers gathered and examined relevant studies to the opportunities of blockchain in the pharmaceutical industry and challenges of blockchain performance. The study identified that one of the largest opportunity areas for blockchain in the pharmaceutical industry is within its supply chain. Issues within the pharmaceutical supply chain involve illegal distribution practices, counterfeit drugs and inefficient drug recall management. With specific challenges and issues identified in blockchain performance, this study proposed the development of a specific blockchain implementation focused on Distribution and Recall transactions within the pharmaceutical supply chain. The proposed system is eyed for a performance evaluation as evaluating the performance of a specific blockchain implementation still yields importance.

Keywords
Blockchain, Hyperledger Caliper, Hyperledger Fabric, Performance Evaluation, and Pharmaceutical Supply Chain

1. Introduction
Blockchain is a type of Distributed Ledger Technology (DLT) that is first used in known cryptocurrency platforms such as Bitcoin and Ethereum. Because of the technology's integration of security, trust, and transparency, the technology is now seen as a notable solution in various industry use cases. Owing to this, early blockchain platforms are being customized to apply the technology in enterprise use, and as these platforms are being tailored to suit the industry requirements, Hyperledger Fabric was developed from the group up with enterprise context as its main goal. As blockchain becomes popular, it is important to assess and evaluate its performance with regard to various use-cases and scenarios that could possibly affect its overall functionality. Performance evaluation in blockchain applications concerns the measurement of essential metrics, such as success rate, average latency, throughput, and resource consumption. Regardless of the advantage of blockchain technology, it still yields technical issues that need to be addressed by conducting a performance evaluation in order for it to become a more improved and realistic replacement to the traditional centralized applications in the market.

Blockchain is a promising solution in multiple industries, and the healthcare sector is an auspicious industry for applications of blockchain, making it the second largest industry to adapt the technology to innovate their 'business as usual' processes. According to IBM, a sector of public healthcare is the Pharmaceutical industry that has a salient responsibility for producing and delivering quality goods to consumers. With such a crucial role in healthcare, the Pharmaceutical industry now turns to blockchain technology to solve predicaments concerning the processes involved in the industry. The disruptive technology brings in optimistic opportunities for the Pharmaceutical industry.

1.1 Objectives

This paper focuses on reviewing literatures regarding performance evaluation of blockchain applications and opportunities of blockchain technology in the Pharmaceutical industry to be able to: (1) identify use cases of blockchain in the Pharmaceutical Industry, (2) identify the challenges in performance of blockchain, and (3) recommend ways to evaluate and analyze the performance of blockchain technology as applied to industry use cases.

2. Literature Review

The following are discussions relevant to the study and its objectives. To answer the first two objectives, relevant literature were gathered then filtered for their eligibility. The chosen studies were discussed in two subheadings entitled 'Challenges in Performance of Blockchain' and 'Opportunities of Blockchain in the Pharmaceutical Industry'.

2.1. Blockchain Technology

Blockchain is a public ledger that keeps a chronological, immutable, and permanent record of all transactions while providing security through a consensus mechanism. This technology aims to be the solution to the problem of having a central authority for keeping and managing data including trust, single-point-of-failure, and a single source of data that is vulnerable to hackers. The ledger that is synchronized among all the peers in the network prevents the occurrence of a single point of failure and a single source of data. To manage trust and identify the source, each transaction is digitally signed by the owner using their private key for authentication. Simultaneous transactions are grouped together in a single component called a block, which is composed of the block version, a hash of the previous block, nonce, Merkle root, timestamp, and transaction data. Figure 1 displays the structure of blockchain as presented in the study of Malik et al (2018).

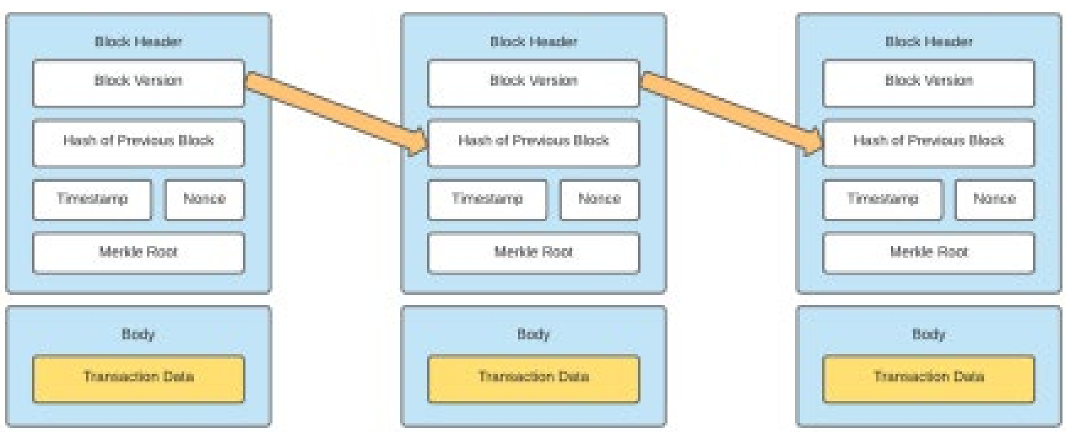

Figure 1. Structure of Blockchain

As blockchain became popular, the enterprise use case for its underlying technology has expanded. However, the current permissionless blockchain cannot present characteristics that are appropriate for enterprise use cases, thus Hyperledger Fabric was designed. Unlike permissionless blockchain which participants are anonymous to each other, therefore untrusted, in a permissioned network, participation is based on permission, therefore participants are identified and trusted. Hyperledger Fabric is an open-source project of Linux Foundation involving people from various industries. It is a framework and a platform for developing permissioned blockchain applications. It has a highly modular and configurable design which allows for versatility and optimization for various industries including supply chain, healthcare, banking, finance, human resources, and digital music. The differentiating features of the technology are better transaction processing and transaction confirmation latency, and it enables privacy and confidentiality of transactions and chain code. Some of the components and key concepts of Hyperledger Fabric are as follows:

1) Nodes - only a logical function. Entities that communicate in the blockchain.
2) Channels - defines the scope of the network and organizations involved. Each channel has a single ledger.
3) Consensus - verifies the correctness of all transactions. It involves complex mathematical computations that keep the ledger transactions synchronized in the network.
4) Ledger - has two data structures, particularly blockchain and world state. The former logs transactions that are shared across the network (i.e., read, write, sign, timestamp) and the latter is a database of tangible or intangible assets derived from the blockchain. The concept of world state is to maintain the current state of the chaincodes' variables.
5) Smart Contracts (chaincode) - reads and writes from the ledger.
6) Transaction - represents changes to a system. It is created when a chaincode is invoked from the application.
7) Application - a means for the users to access the blockchain through API. This is where transactions are submitted which invokes smart contracts with a set of parameters.
8) Membership Services Provider (MSP) - a PKI-based abstract component that uniquely identifies identities and roles for a channel.
9) Ordering Service - nodes that order and endorse transactions to peers. This service may use Kafka, Raft, or Solo for its implementation.

2.2. Performance Evaluation of Blockchain Technology

2.2.1. Challenges in Performance of Blockchain

As time passes by, numerous blockchain frameworks have been widely used in various industries adapting its flexible platforms to support applications in industry use cases. Despite the development and advancement of blockchain as applied to industry use cases, several technical challenges are still faced in terms of the overall performance and functionality of blockchain technology concerning its network workload. With the use of specific metrics, such as latency, throughput, and scalability, the network workload was evaluated and analyzed in terms of its technicalities in the study of Kuzlu et al. (2019). In addition, legal issues are also one of the challenges faced by blockchain technology, especially in the healthcare and/or pharmaceutical industries. In the study of Wright (2019), the implementation of blockchain may possibly yield diverse legal issues concerning trust security of blockchain-based applications. Blockchain's security and privacy have been studied more often than its performance, thus, the need for further performance evaluation to enhance the performance of blockchain technology as applied to the industry use cases. Blockchain consists of a broad range of settings which influences and affects the overall performance of a blockchain-based application. One of the main challenges in the performance of blockchain as mentioned by Behesti et al. (2021) is the varying number of peers in a blockchain network. An increase in the number of peers in a network may affect the performance characteristics of a blockchain technology. Likewise with the increased number of varying peers, as the number of input transactions increases the performance metrics of the blockchain technology gets also affected. It is observed that the higher the number of inputs in a network, the longer the execution time and more latency is reflected. Similar to all of the other studies discussed, the study of Georges et al. (2020) have discussed the challenges in performance of blockchain and have considered network workload as one of the main issues faced in terms of the blockchain's performance. Consensus layer affects the general network performance of a blockchain technology because it is significantly dependent on the type of consensus algorithm used in a blockchain application. With all of the challenges encountered in blockchain applications, it is important to further conduct studies focusing on performance evaluation to be more aware of blockchain's overall performance extent.

2.2.2. Evaluation Method

In recent years, blockchain technology has been applied in various industries in hopes of having a more improved storing system and handling of data in a decentralized ledger. However, despite it being used by different industries for transparency and traceability, some individuals are still not sure about its performance capability (Behesti et al., 2022). Several studies have presented methods on how to evaluate and analyze blockchain technology using Hyperledger Fabric platform in order to improve its overall performance and functionality. The study of Kuzlu et al. (2019) has conducted a performance analysis on a Hyperledger Fabric framework which evaluated the performance of a Hyperledger Fabric blockchain in terms of throughput, latency, and scalability. In a blockchain network, throughput is measured as the successful transactions per second (TPS), latency is the response time per transaction in seconds, and scalability can be measured as the number of participants that the blockchain could accommodate which was represented by the number of simultaneous transactions in the study. The tool used in the study to test a specific blockchain implementation was Hyperledger Caliper and its results were utilized to evaluate its performance.

In this study, a set of parameters were used for performance evaluation of blockchain's throughput, scalability, and latency.

2.3. Opportunities of Blockchain in the Pharmaceutical Industry

Blockchain has been greatly used in various industries in other countries to capitalize on technological advancements in society. Supply chain is one of the most common use cases in the Pharmaceutical Industry. Functions of supply chain management includes the ability to track goods throughout the supply chain (Dubey et al. 2020). The opportunity of blockchain in the pharmaceutical supply chain is to provide traceability, transparency, security, and privacy to the drugs' system. Traceability can be defined as "the ability to track and trace information" at the granular level which then creates transparency or the ability to access or share information across the supply chain (Sunny et al. 2020). With blockchain technology, the distribution process in the pharmaceutical supply chain is evident and can give transparency to the drug's provenance as each transaction is recorded and logged in a distributed ledger system (Nageswar and Yellampalli 2019) Its cryptographic and decentralized system offers security in a way that if one node fails, the others will not be affected which makes the technology more beneficial than centralized systems (Azzi et al. 2020). One of the problems in the pharmaceutical supply chain is the illegal trade of medications. According to the study of (Ahmadi et al. 2020), problems concerning the pharmaceutical supply chain include the increase of medicines being sold in the black market. Available medicines in black market does not ensure the legitimacy of the drug. The use of traceability blockchain application can be used in keeping track of transactions within the pharmaceutical supply chain, specifically with regards to the transportation and distribution of drugs from one intermediary to another. It can also be used to validate the origin or previous transactions of the supplied drugs. In addition, the study of (Badhotiyaet al. 2021) assessed the application of blockchain technology within the pharmaceutical supply chain and has discovered that the characteristics of the technology works out in detecting falsified drug products within the supply chain. Blockchain traceability can provide a secure means of keeping track of the transactions to lessen the distribution of falsified drug information and invalid exchange of supplies between the intermediaries. Furthermore, the study of Uddin (2021) proposed a Hyperledger Fabric blockchain-enabled drug traceability system (Medledger) as a solution to counter fake and counterfeit drugs in the pharmaceutical industry. The authors stated that the critical characteristics needed for drug traceability include privacy, trust, transparency, security, authorization and authentication, and scalability. The system, Medledger, is a track and trace blockchain-enabled system that is developed on Hyperledger Fabric blockchain platform utilizing chaincodes to ensure efficient and secured drug supply chain transactions. The study of (Bamakan et al. 2021) focused on the application of blockchain in the pharmaceutical cold chain. According to their study, the Pharmaceutical cold chain, a temperature-controlled supply chain, is much more prioritized when it comes to management. Applications of blockchain in this industry include providing solutions to data privacy, speed, compliance and cost, and speed. In addition to the opportunities discussed by the other studies concerning the use of blockchain technology as applied in the Pharmaceutical Industry use case, one of the use cases that blockchain technology can be applied to is drug recall. The proposed system in the study of Agrawal et al. (2022) focuses on product recall using blockchain technology. This is to address the critical issues of defective drugs in most manufacturing companies. The blockchain technology in this study acts as a monitoring system for distributed drugs in the supply chain considering that blockchain technologies are known to have an improved manner of securing transaction processes. Moreover, it also aims to address the time and cost transacted throughout the distribution of product from manufacturers to the end-users. Therefore, blockchain technology gives way for the product recall to be automated and transparent in the pharmaceutical supply chain.

3. Methods

The methods of this study will be focusing on gathering literatures relevant to the study. Two reliable databases will be explored for literature: IEEE Xplore (published by Institute of Electrical and Electronics Engineers) and ScienceDirect (published by Elsevier). After the gathering stage, filtering of the literature will be done to ensure that chosen literature to be reviewed is significantly relevant to the study. The included studies will then be reviewed Figure 2 presents the flow of procedures for this literature review.

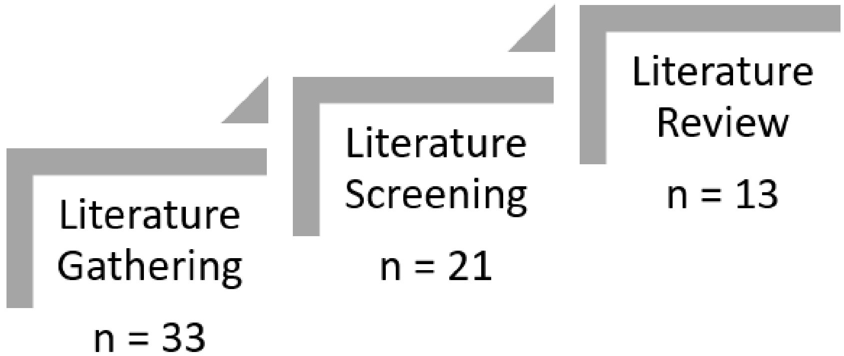

Figure 2. Flow of Procedures

4. Data Collection

To attain the first two objectives of this paper, studies relevant to opportunities of blockchain in the pharmaceutical industry and challenges in performance of blockchain were collected from the aforementioned databases. This initial process is described as the gathering stage. The goal for this stage is to collect studies that have titles relevant to the two above-stated sub-topics. Keywords such as “performance”, “evaluation”, and “blockchain” were used as search queries. A total of 33 studies were gathered from the two databases, 16 in IEEE and 18 in ScienceDirect. From the gathering stage, the studies were screened based on the relevance of their abstract. From the screening stage, the total studies are down to 21: 9 in IEEE and 12 in ScienceDirect. The 21 studies were then filtered for eligibility based on full-text relevance. From this, a total of 13 studies were left: 5 in IEEE and 8 in ScienceDirect. These studies are then reviewed and analyzed. The review of the eligible studies are discussed in the Literature review under two subheadings: Opportunities of Blockchain in the Pharmaceutical Supply Chain and Challenges in Performance Evaluation of Blockchain. Figure 3 represents the figurative procedure of the data collection.

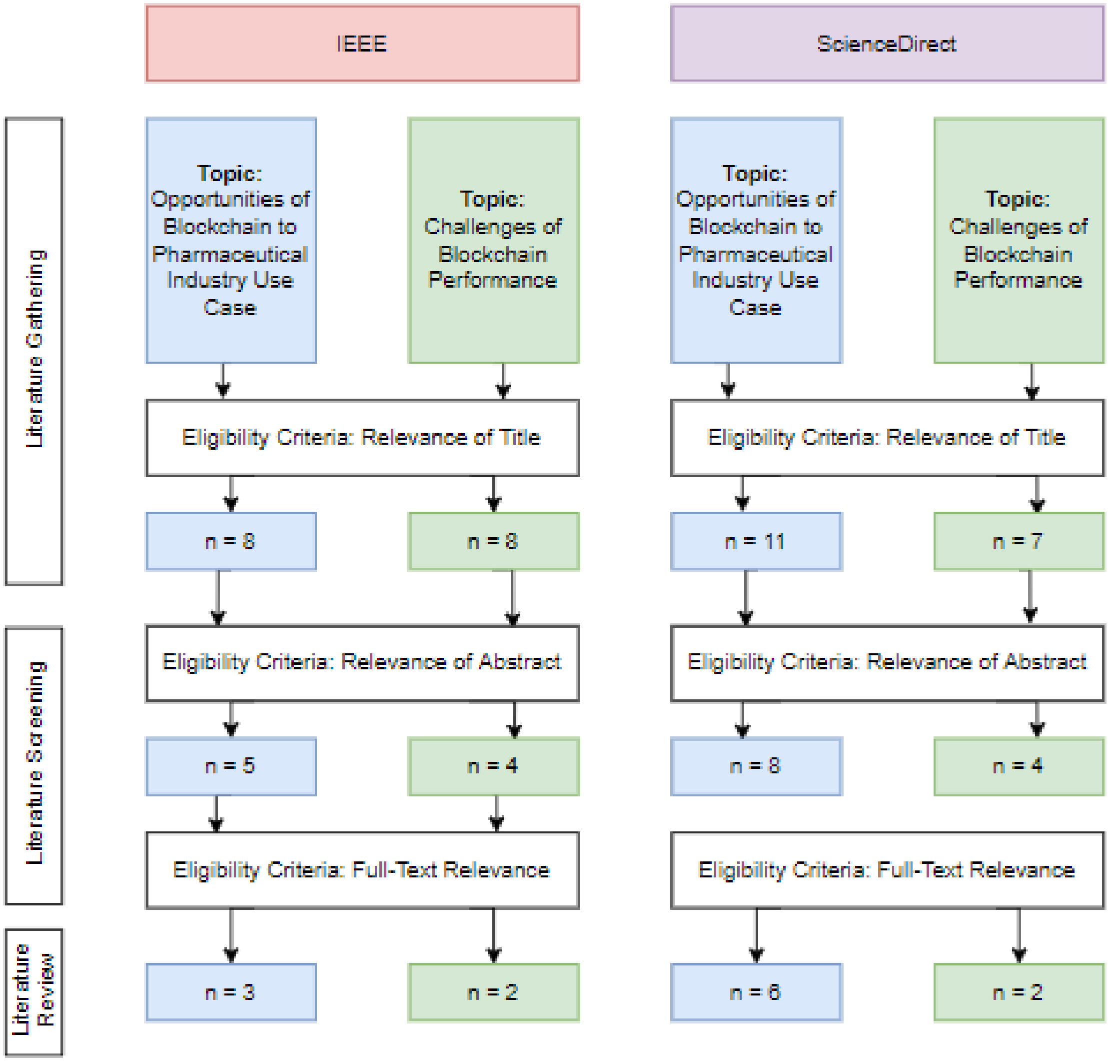

Figure 3. Data Collection Procedure

5. Results and Discussion

From the gathered studies, a total of 13 studies were eligible for a full-text review and analysis. Discussions about the eligible studies are made under the Literature Review. The following tables present the results of the review and analysis done of the qualified studies. Following the numerical results of the study, a performance evaluation of a blockchain platform (Hyperledger Fabric) is proposed to a specific use case of the pharmaceutical industry. The proposed system is prospected as a future development.

5.1 Numerical Results

To answer objective 1, literature was gathered relating to opportunities of blockchain in the pharmaceutical industry. A total of x literature was gathered relating to the sub-topic. These literatures are discussed in the Literature Review under sub-heading Opportunities of Blockchain in the Pharmaceutical Industry. Table 1 presents the tabulated results for a clear identification of the possible pharmaceutical industry use cases to be block chained.

Table 1. Pharmaceutical Industry Use Cases for Blockchain

Pharmaceutical Industry Use Cases	No. of Studies	References

Traceability System of Counterfeit Drugs for Pharmaceutical Supply Chain	5	Uddin (2021); Badhotiya et al. (2021); Kumar and Tripathi (2019); Saindane et al. (2020); Ahmadi et al. (2020)
Drug Recall Management System	2	Lin and Wu (2019); Agrawal et al. (2022)
Traceability System to Counter Illegal Distribution Practices	1	Ahmadi et al. (2020)
Pharmaceutical Cold Chain	1	Bamakan et al. (2021)
Traceability System for Supply Chain Transparency	1	Sunny et al. (2020)

From table 1 above, it can be inferred that blockchain technology has many opportunities in the Pharmaceutical supply chain, focusing mainly on traceability of counterfeit drugs, which is seen as a current-day problem among the pharmaceutical industry. A management system for drug recalls can also be seen as an optimistic opportunity for blockchain application.

Table 2. Identified Challenges in Blockchain Performance

Challenges in Blockchain Performance	**No. of Studies**	**References**
Network Overload	4	Kuzlu et al. (2019); Wright (2019); Beheshti, et al (2020); Georges, et al. (2021)
Varying Number of Peers	2	Beheshti, et al (2020); Georges, et al. (2021)
Block Size	1	Georges, et al. (2021)
Consensus Algorithms	1	Beheshti, et al (2020)
Legal Issues	1	Wright (2019)

Table 2 presents the different factors that influence the performance of blockchain applications. Network overload pertains to the transactions that happen within a blockchain network.

5.2 Proposed Improvements

The tabular results have identified that the opportunities of blockchain in the pharmaceutical industry are promising especially in the pharmaceutical supply chain. As discussed in the Literature Review, some of the concerns in the pharmaceutical supply chain involve counterfeit drugs, inefficient drug recall practices, and illegal distribution practices. The information gathered from the literature review have shown the importance of conducting further performance evaluation of blockchain technology in specific industry use cases. With this, the study proposes to develop a Hyperledger Fabric Blockchain-based Application as applied to the Traceability of Distribution and Recall Transactions between Distributors and Retailers of the Pharmaceutical Supply Chain and conduct a Performance Evaluation based on the blockchain application's throughput, latency, and scalability using Hyperledger Caliper. Hyperledger Fabric is the proposed platform for developing the application as it is specifically designed for industry use cases. Hyperledger Caliper is a benchmarking tool used to measure the specific metrics of performance for blockchain applications. The proposed process flow as reflected in figure 4, adapts the Hyperledger Fabric framework for the traceability system of the distribution and recall transactions in the pharmaceutical supply chain. The process begins with the user invoking a smart contract through the client application, which is the component of the Hyperledger Fabric that enables users to interact with the blockchain network. The smart contract is designed to trace the physical flow of drugs within the supply chain. It has the functions of add, buy, transfer, delete, and query drugs.

The process of distribution starts when batches of medicines are dropped off to the distributor, therefore they have the capabilities of adding a drug to the blockchain, transferring drugs during the distribution process, deleting drug in the world state when transferred to the manufacturer for disposal, and querying drug information for traceability, whereas the retailer is limited to the functions of buying batches of drugs, transferring drug for the recall process, deleting the drug when disposed of, and querying drug information to look for the list of available drugs and for traceability. When a user invokes the smart contract through the client application, the app will create and submit a transaction proposal to the peer nodes which will then endorse the proposal to the nodes involved in the transaction and have it signed (i.e., peer nodes of distributor and retailer organization). After endorsement, the peer nodes will create and submit a proposal response that contains a response value to the client application. If the user only desires to query the drug information, the requested information will be returned, and the querying process ends. However, if the user desires to update the ledger (i.e., add, update, or delete drug on the world state), the client application will submit the transaction to the ordering service for it to create blocks of transactions to be committed to the ledger. The blocks will then be distributed to the peer nodes for them to commit the changes and update their ledger as well. The added or updated drug information will be applied to the world state database and the hash of the drug transaction will be stored on the blockchain which will serve for the traceability for the distribution and recall transactions, as well as for tracing any modifications to the drug information on the ledger.

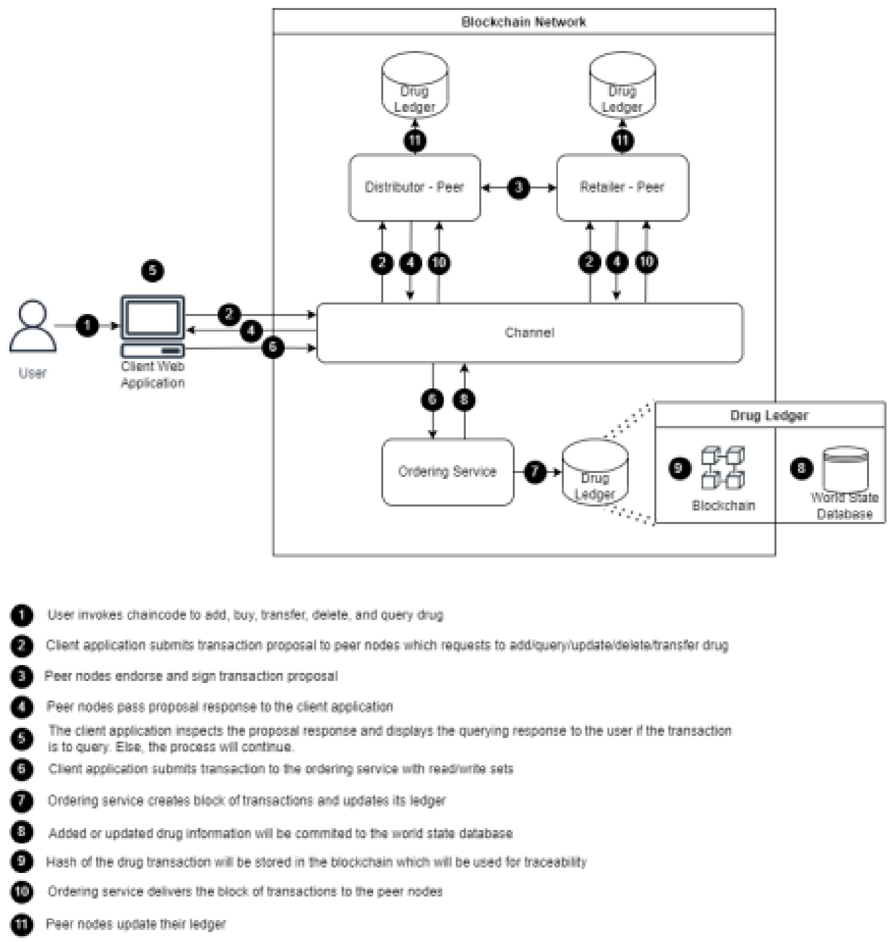

Figure 4. Process Flow of Proposed Application

The network architecture (as shown in figure 5) reveals the design of the blockchain network connected to the application that is used to test the developed smart contract and client application. It presents the components that are existing in the Fabric test network and their representation in the traceability system, including the channel, smart contract and ledger. There are two peer nodes which maintains the developed smart contract and drug ledger, one for the distributor and the other for the retailer; one ordered node from Raft ordering service, which organization will be assigned to the distributor since it is the host company that provides drugs in bulk to the retailer; one channel that will be created upon the configuration of the blockchain network, and it is where the participating nodes of the traceability system will be deployed. Moreover, each organization has their own certificate authority to manage identities. Each component is deployed on different docker containers on a local computer.

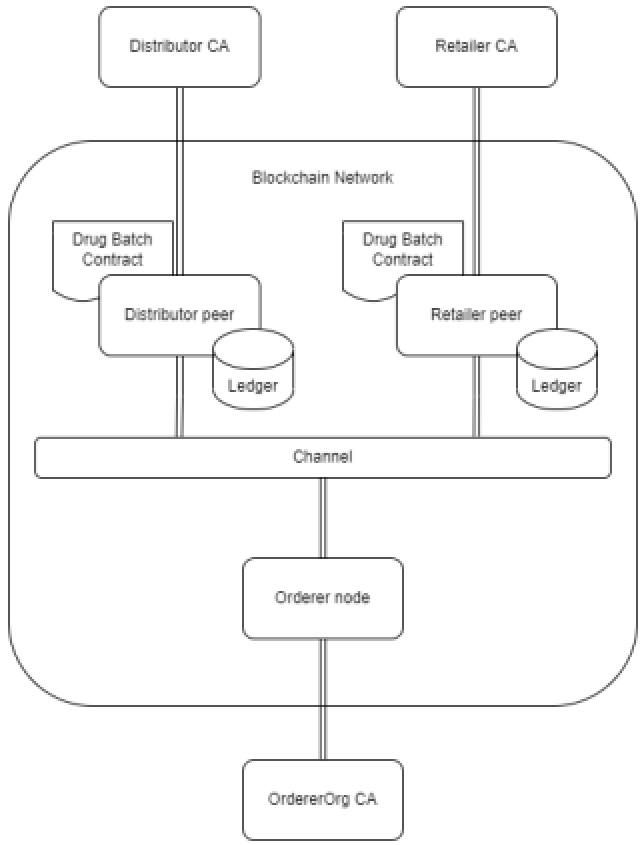

Figure 5. Proposed Network Architecture Design

Figure 6 defines the structure of the implemented blockchain system. The components include the user, client application, Fabric gateway, and the Fabric network. The user may be the distributor or retailer of the Pharmaceutical supply chain. The functionalities accessible are dependent on their identities that are identified and managed by the certificate authority. The user employs the client application to invoke the drug batch smart contract either to update or query the ledger. The client application is deployed on the local machine, utilizing port 8080 to access its web interface. It is built with Vue.js, a front-end framework to provide a user-friendly interface to the users, and Hyperledger Fabric's Node.js API, a high-level API to enable the application developers to implement smart contracts. For the server side, Node.js application server which creates APIs for the client web app and uses the Fabric SDK, also known as the gateway to interact with the blockchain network. When the client application submits a transaction, the SDK will communicate with the Fabric network to process the transaction proposal to query or invoke the smart contract. The Fabric blockchain network is deployed on Docker with each component in a separate container. It comprises peer nodes that endorse and validate the transactions, and a single node ordering service using Raft consensus which creates blocks and delivers them back to the peer nodes who keep the ledger and chain code. The Node.js application server is also responsible for the PUT and GET requests to the CouchDB state database which is processed before the blockchain is updated.

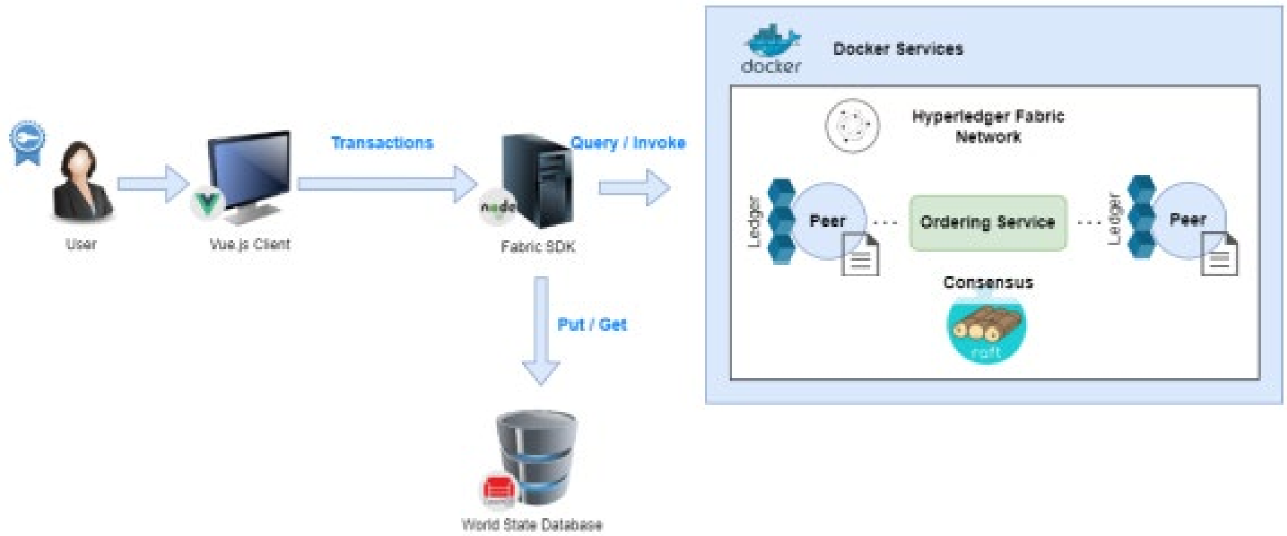

Figure 6. Proposed System Architecture Design

6. Conclusion

Based on the information gathered and provided in this study, many challenges concern the performance of blockchain applications, requiring further evaluation of the technology's performance for a specific industry use-case. As the technology is continually being customized for enterprise use, performance should be one of the major criteria in enabling the technology.

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Biographies

Mary Jane C. Samonte has a double bachelor's degree in computer education and information technology. She also has two post graduate degree; Information Technology and Computer Science. She finished her Doctor in IT with a study focusing in Deep Learning. She has a wide range of research interests that are centered around educational technologies, gamification, mobile and ubiquitous learning, digital game-based learning, artificial intelligence in education, e-health, assistive technology, natural language processing, green computing and data analytics-based studies.

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