# Blood and Product-Chain: Blood and its Products Supply Chain Management based on Blockchain Approach

Phuc Nguyen Trong, Hong Khanh Vo, Luong Hoang Huong, Khiem Huynh Gia, Khoa Tran Dang,
Hieu Le Van, Nghia Huynh Huu, Tran Nguyen Huyen, The Anh Nguyen, Loc Van Cao Phu,
Duy Nguyen Truong Quoc, Bang Le Khanh, Kiet Le Tuan
FPT University, Can Tho City, Viet Nam

***Abstract*— This paper provides a novel implementation of blockchain technology, and data is stored in a decentralized distributed ledger to assist information protection in blood supply chain management and prevent data loss or identity theft. The present blood supply is used exclusively from the blood of volunteers (known as donors), making blood and its derivatives one of the significant roles in treating diseases today. In particular, depending on the type of product extracted from the blood (e.g., red blood cells, white blood cells, platelets, plasma). They require different procedures and storage environments (e.g., time, temperature, humidity). However, the current blood management processes are done manually - where all medical staff does all data entry. Additionally, data about the complete blood donation process (e.g., blood donors, blood recipients, blood inventories) is held centrally and is challenging to examine accurately. Therefore, ensuring centralized data security is extremely difficult because of stealing personal information or losing data. In this study, we present the blockchain technology-based blood management process and offer Blood and Product-Chain, a decentralized distributed ledger that stores data to address these restrictions. Specifically, we target two main contributions: i) we design the Blood and Product-Chain model to manage all relevant information about blood and its products based on blockchain technology, and ii) we implement the proof-of-concept of Blood and Product-Chain by Hyperledger Fabric and evaluate this in the two scenarios (i.e., data creation and data access).**

***Keywords*—Blood donation; blockchain; hyperledger fabric; blood products supply chain**

## I. Introduction

The rising need for medical supplies and services, particularly blood, due to which it is necessary to improve blood management. Blood has many components, such as red blood cells, white blood cells, platelets, plasma, and other features [1]. Each blood component serves a specific function in the human body; for example, red blood cells help transport oxygen to cells/parts of the body, and a liter of blood can sustain the life of a premature baby for two weeks, and an accidental blood loss trauma sufferer may need 40 or more units of blood to survive. Therefore, blood is an essential medical resource, and blood management is a fundamental problem the human species needs to solve.

However, all blood collected must be analyzed before being transferred to the recipient. One important part of this work is reducing the risk of infection by transmission [2]. Specifically, the common infection mechanism is hepatitis B virus (HBV), human immunodeficiency virus (HIV), and hepatitis C virus (HCV). Besides, blood is generally collected from volunteers; hence the supply chain for blood and its products is impacted by a lack of donors, a delay in testing, and, most importantly, the short shelf life of perishable blood products [3]. However, reducing these risks necessitates a difficult process and expensive blood supply chain management.

It can be argued that optimizing the blood supply chain management process is the key to solving the current blood shortage problem in medical facilities. The traditional model is depicted in Fig. 1. Specifically, the blood donation center will directly contact donors (i.e., in case of an emergency) or organize events calling for community blood donations. Donors must undergo a health assessment before donating blood. Then, this raw blood is converted into different components such as red blood cells, white blood cells, platelets, and plasma. The amount of blood and its products after censorship will be partially transferred to medical / health care centers (periodically), or the rest will be stored in the warehouse in case of emergency. It is also important to consider how blood is distributed and stored because different blood components have varied usage requirements and lifespans.

Besides, the information of blood, recipients, and donors is stored in a centralized server. Specifically, information about donors is divided into many areas. If those donors are not at their residence address, they cannot participate in the system. Additionally, the information stored is very private for donors and recipients (i.e., it comprises information unrelated to blood illnesses). Risks related to centralized storage include user misconduct and information loss. To solve a series of important issues mentioned above, we applied blockchain and smart contract technology (i.e., Hyperledger Fabric platform).

Blockchain technology is known for its outstanding features of transparency and immutable content. Picha Edwardsson et al. studied the possibility of using blockchain technology to create a secure, community-facing information verification database with the goal of creating a solution that could improve the reliability of verifying information and monitoring each authenticity verification process for digital content, including images and videos. The paper indicates that blockchain is not yet ready to be directly applied to fact-checking processes in a real-world scenario. The study also shows that the application of blockchain to verify a scenario is entirely possible and highly reliable and transparent [4]. Several approaches address

these problems by applying Blockchain techniques in the other environment (e.g., cash-on-delivery [5], [6], [7], healthcare [8], [9], [10], supply chain [11], [12], [13], and others [14], [15], [16]).

Therefore, this paper focuses on building Blood and Product-Chain: the management transportation of blood and its products based on blockchain technology. The main contributions of Blood and Product-Chain are two-fold. i) we design the Blood and Product-Chain model to manage all relevant information about blood and its products based on blockchain technology, ii) we implement the proof-of-concept of Blood and Product-Chain by Hyperledger Fabric and evaluate this in several scenarios.

In this paper, the structure is organized as follows. The next section of the paper presents a literature review of relevant issues. The Blood and Product-Chain overall architecture and implementation are shown in two following sections (III and IV). Section V describes the framework and benefits of the proposed system via evaluation. Finally, Section VI dedicates the conclusions and future research opportunities.

## II. Related Work

### A. Healthcare Systems based on Blockchain Technology

There are several blockchain-based approaches in terms of healthcare/blood donation management systems. For example, Du et al. [17] and Son et al. [18] used medical centers (i.e., hospitals) to store data and manage access and those hospitals. Specifically, they categorize two types of medical data protection policies: global for all data shared outside of the medical center, and local, which is accessed only by individuals at the medical center. medical (i.e., doctor, nurse). However, one of the major limitations is that through this solution, patients do not have full control over their data as the data and policies are stored in the hospital. Some other approaches build a user-centric (i.e., patient) model, which has full discretion to share their personal data with providers/health care facilities. economic (i.e., in a medical setting). For instance, Makubalo et al. [19] have summarized the above approaches in their publication. They argue that the methods of building a user-centric health data sharing system are facing a lot of difficulties due to the limitations of the method of building centralized data system (i.e., data) stored and processed centrally in cloud servers). Yin et al. [20] introduced a patient-centric system built in the cloud with a data collection layer, data management layer, and medical service delivery layer based on the medical records of the patient. To protect data privacy, many approaches have adopted attribute-based encryption (ABE), one of the most common encryption schemes used in cloud computing, to define patient data object. Depending on the context, the policy tells to lose (or not) grant the corresponding access rights. For example, Barua et al. [21] proposes an ABE-based access control model based on patience and privacy protection; Chen et al. [17] described a new framework with a cloud-based, privacy-aware Role-Based Access Control model that can be used for control, data traceability, and access allowed access to healthcare data resources. Methods for applying the Access Control model are also introduced for dynamic policies [22], [23] or protection policies for both security and privacy [24]. Ateniese [25] proposed a new framework that makes it possible to re-write or compress the content of any number of blocks in decentralized services exploiting the blockchain technology.

One disadvantage of centralized storage in the above approaches is transparency [26], [27]. To address this issue, Lam et al. [28], [29] demonstrated the implementation of a micro services-oriented software architecture for middleware that collects, stores, and traces data in a centralized manner in order to provide data analysis. However, for the specific requirement (e.g., blood donation w.r.t supply chain), we need a specific model to balance the demand (i.e., blood recipients) and supply (i.e., the time for the next round of donors). To apply these advantages, many studies focus on blockchain-based approaches for the blood supply chain donation issues, which contribute to the improvement of demand and supply requirements.

### B. Blood Supply Chain Management Systems based on Blockchain Technology

Trieu [30] proposed the cold chain model for blood donation based on the Hyperledger Fabric platform called BloodChain.[1] They only considered the blood data and ignored its products as well as the other storage requirement for them. The main contribution of the two above papers is only to verify the information of the recipients to the donors. These papers are very soon introduced in the large picture of this problem. Similar to BloodChain, Lakshminarayanan et al. [32] presented a blood supply chain management system based on Hyperledger Fabric to ensure the transparency requirement in terms of blood units between donors and recipients. To detect the location of the donor's blood, on the other hand, Toyoda et al. [33] provided hardware-based approaches (i.e., RFIDs) in combination with the blockchain to track the status of the blood donation. However, there are some limitations to the solutions above. For example, the verification of the system proposed in incomplete due to the lack of evaluation analysis. Furthermore, the monitoring solution proposed in [33] is limited to monitoring blood bags only, and it does not guarantee the traceability of blood components (i.e., red blood cells, platelets, white blood cells, platelets and plasma). Since different blood components have other shelf lives and storage temperatures, the order of the user preference should also be considered.

Moreover, the authors in [34] have proposed a decentralized solution based on an Ethereum-based blockchain for blood transport. In their design, certified blood donation centers (CBDCs) are the only privileged members with the right to create smart contracts to manage the entire system. Donors were recognized through an identifier such as their social security number and password. Besides, Peltoniemi et al. [35] discussed how decentralized blockchain was for plasma tracking and management. In more detail, the system stores donors' information before separating their plasma. They then maintain the origin of the plasma and identify poor blood quality. Another solution based on Hypeledger was proposed by Kim et al. [36] to build a blockchain-based blood supply chain management system. For the GDPR privacy compliance, Campanile et al. [37] presented literature solutions and design

[1]Their model is the extended version of [31].

implementation in the context of a traffic management system for the Internet of Vehicles based on the Pseudonymization/Cryptography solution, evaluating its viability, its GDPR compliance and its level of risk. In addition to the fact that this solution is based on a private blockchain, to protect the privacy of donors, it only focuses on tracing information related to the supply chain, but it does not track the identity of the donors as well as the part of a blood unit.

To sum up, none of the above blockchain-based solutions guarantees data privacy while providing a robust system for tracking and managing the donated blood supply chain. In addition, the above methods focus only on managing blood information rather than considering their products (i.e., red blood cells, white blood cells, platelets, and plasma). This is extremely important because each product has different management conditions and usage times. Our proposed solution captures various aspects of the blood donation system such as collection, distribution, request and delivery of blood units. It ensures that all these aspects are captured as decentralized, traceable, accountable, transparent, secure, and auditable. Our solution tracks all necessary stages of the donated blood unit cycle, from donation until consumption.

## III. Blood and Product-Chain Architecture

To address the limitation of the traditional approach which mentioned in Section II, we first introduce the overall architecture, which provides the overview model. In this model, we provide the key components (i.e., actors) as well as the relationship among them. After that, the relationship and main steps are presented in the detailed model which highlights the Blood and Product-Chain in nine main steps.

### A. Overview Model

There are several approaches that provide the traditional model for the blood supply chain (e.g., [38]). In this section, we target the overall architecture of the Blood and Product-Chain model before focusing on the two main processes that store the donor's information in the distributed ledger and use this info to contact the donor candidate for blood donation in the next round.

For the first target, Fig. 1 shows the three actors who have the main role in our proposed system, namely the Doctor/Nurse, recipients, and donors. Whereas, the remaining components represent the medical facilities as well as the blood-collection/protection centers/ways (e.g., blood transporter, blood bank), respectively. All the corresponding data of the facilities or actors are stored and processed in the distributed ledger. This process allows the stakeholders to verify their data before using it. This also increases transparency for the whole system (i.e., accessing and performing blood data/transferring the blood of the donors to the other facilities).[2] Thereby, medical facilities can retrieve and confirm data related to the treatment process.

For the second target, we present the two main blood donation process in Fig. 2 and 3 for the donor's information and contacting process in medical facilities, respectively. The main contribution of this task is that we consider the decentralized system, where a certain facility is allowed to contact the other donors, who donate their blood in another hospital, rather than only their list.

[2]Regarding the collected data for each donor, we store the blood type, number of blood donations, and its metadata (e.g., time, location), as well as other personal information in a decentralized approach (i.e., distributed ledger).

### B. Detailed Model

Blood and Product-Chain is presented in Fig. 4 with eight main actors including medical staff (nurses, doctors), recipients, donors, hospitals (i.e., clinic, medical clinic, mobile blood collection unit), hematology hospital, blood bank, blood transporter, and distributed ledger. Blood and Product-Chain focuses on building a Blockchain-based blood supply chain model, where the transport of blood between medical facilities plays an important role and reduces the pressure on the hematology hospital in the blood collection process from donors. Specifically, step 1 collects the treatment history of recipients through the records of nurses and doctors (i.e., medical staff). All this information will be updated to the hospital where the recipients are being treated (Step 2). In the event that the amount of blood and blood products is insufficient during treatment, the hospital will submit a request by updating the current status of blood amount on the distributed ledger. All information about blood volume, blood type and other special requirements are shared with relevant parties in Blood and Product-Chain (Step 3). At this step, the data of medical facilities is also updated. Blood volumes in a medical facility's system can be shared with other facilities to optimize blood availability. To do that, the establishment needs to update the status and send a request to the transporter about the collection and receipt locations of blood and blood products (Steps 4 and 5). After that, the transporter must always update the progress of the shipment on the distributed ledger (Step 6). All information about location, time, and order information can be verified and moderated by the stakeholders. We continue to consider another case where the requested amount of blood and blood products is not available in the system, i.e., the state of blood and blood products is not available. This request is forwarded to the hematology hospital (Step 7). Step 8 describes the procedure for checking the amount of blood and blood products in stock. Step 9 contacts the donors to schedule a blood test and donation if the requested amount of blood is unavailable. The list of donors is gathered from previous blood donation sessions and selected the candidates with the closest addresses.

## IV. Implementation

### A. Permission Diagram

Fig. 5 presents the working mechanism of the request authentication process in this paper. Specifically, we built two organizations with corresponding encrypted material certificates, each organization includes two users and two peers. Each peer is responsible for maintaining the version of the ledger so that the network and data can be maintained even if other peers are shut down.

When the user initiates a request and sends it to the service. The back-end service processes the data and sends it to the smart contract API. When receiving the request and the data, the smart contract sends this to the peers in the network

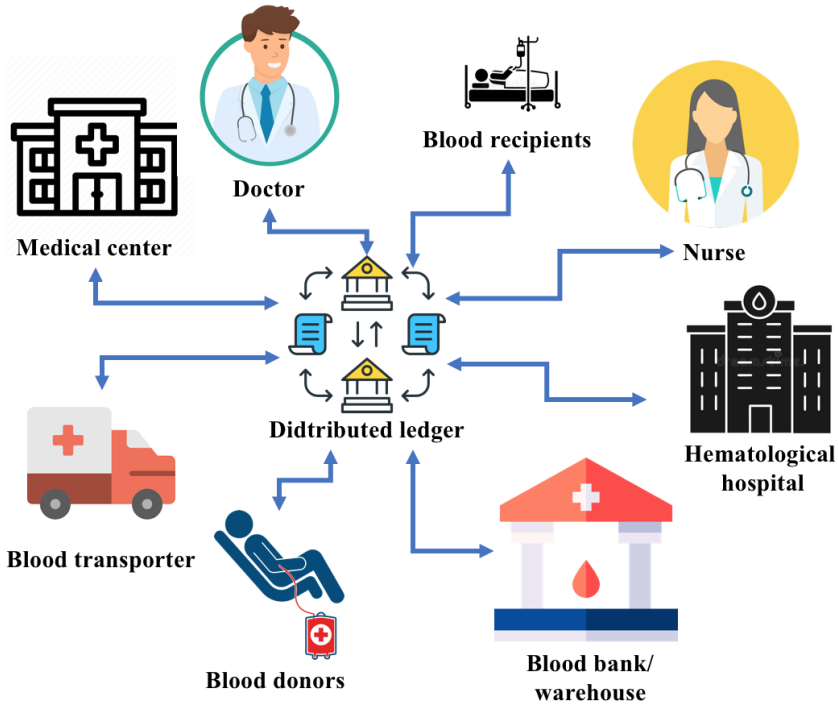


Fig. 1. The Overall Architecture of the Blood&Product-Chain.

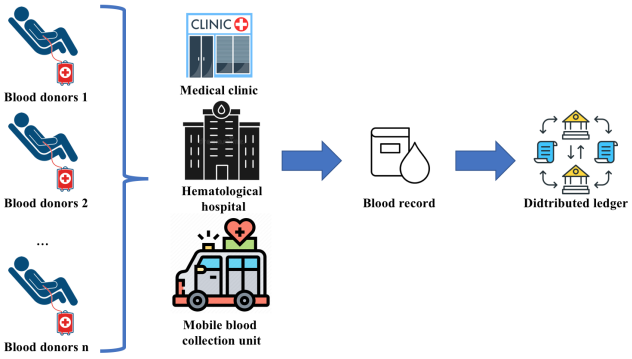


Fig. 2. The Storage Process of the Donor's Information in Distributed Ledger.

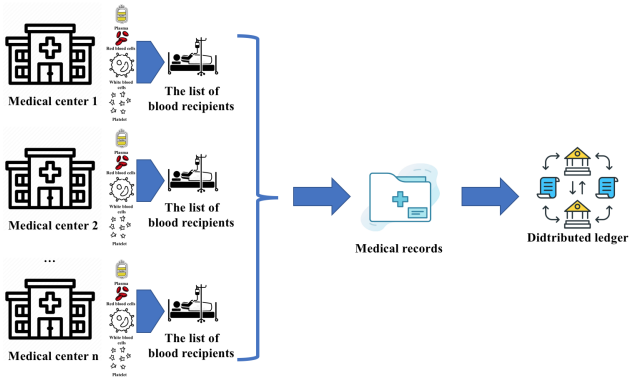


Fig. 3. The Storage Process of the Medical Center's Information in Distributed Ledger.

for authentication and data interaction purposes. During the creation, querying or updating data processes, peers check the identity of the request to decide whether to allow access to the data at the distributed ledger. If the identified user of the request is not defined in the data collection, the system denies access and sends a message to the back-end API to notify the user; the system allows access and proceeds with further processing steps.

### *B. Hyperledger Component*

The model in this paper is implemented on the Hyperledger Fabric platform. Fabric is a permissionless blockchain platform that integrates smart contracts, the storage of data to the distributed ledger is controlled through the smart contract APIs, from which the data is simplified and easily traced. Each request that goes through the smart contract is verified with public and private key pairs. In other words, if the user does not exist in the system, the system is better protected from malicious requests outside the system.

The Fabric system in this paper includes two organizations. Each organization consists of two peers to store smart contracts, where each peer registers two users and is authenticated with public and private key pairs. The components of the model are shown in Fig. 6

When user devices access the system to initiate/query or update data for a particular transaction, requests are sent from the client to the services of the existing system. Then, these services send access information to the peers belonging to the organization located in the blockchain network. At this step, the peers conduct verification of that user's key pairs, and if the successful peer authentication process proceeds to send information to the smart contract with the transaction

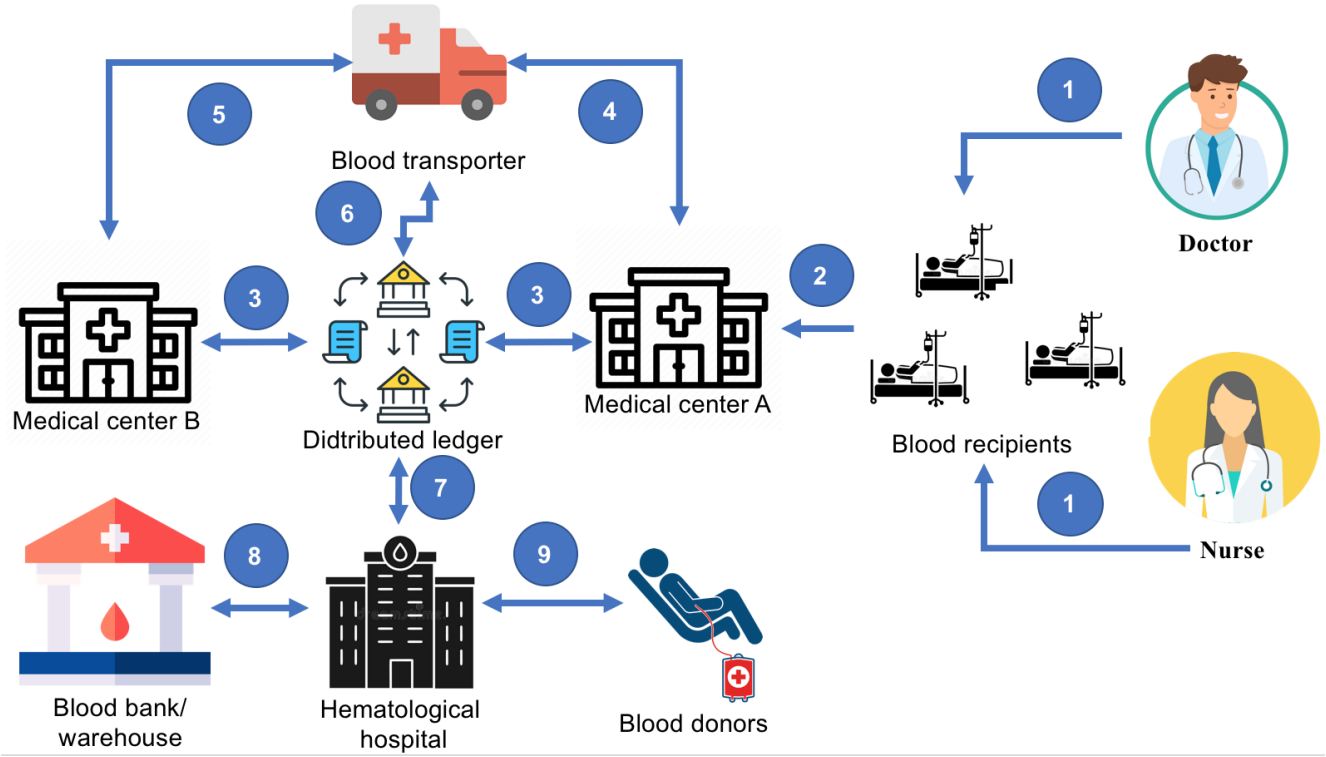


Fig. 4. The Detailed Architecture of the Blood & Product-Chain.

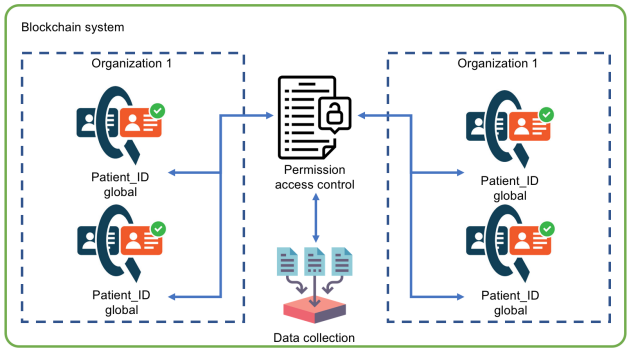


Fig. 5. Permission Diagram.

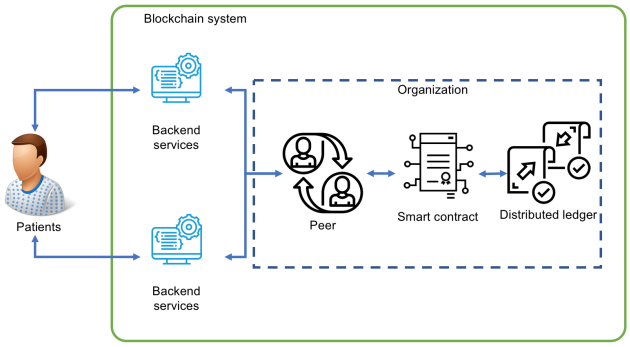


Fig. 6. Hyperledger Fabric Component.

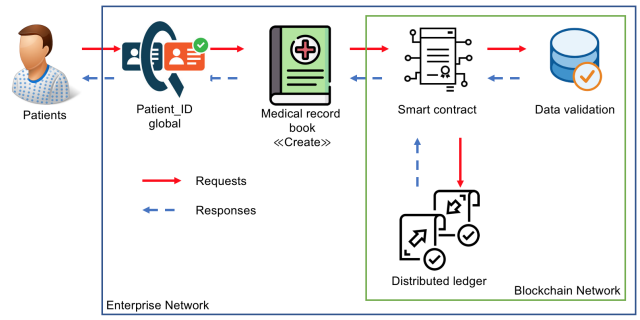


Fig. 7. Initializing and Storing the New Data.

type declared in a smart contract requested by the user, the smart contract will go through the designed features function to access the distributed ledger to initiate/query or update specific data.

### C. Blood Pro-Chain Diagram

One of the most important parts of the model lies in the validation and interaction with the blood records described in Fig. 7 and 8. In particular, the main functions include initializing and querying the blood records.

Fig. 7 depicts the process of storing new record data (e.g., blood and its products). In step 1, when the user initializes information of a blood record, the data is sent to the back-end service of the health center's information management system. In the next step, the back-end APIs (i.e., backend) check, authenticate and initialize the default values, then pass

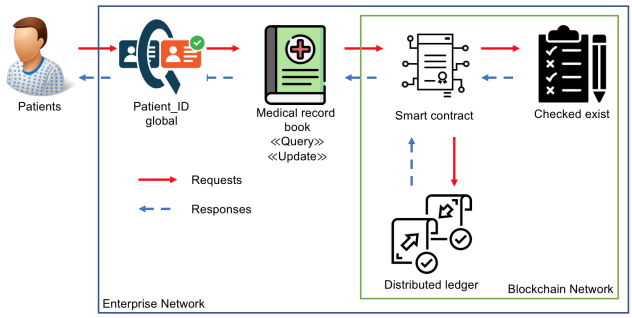


Fig. 8. Retrieving/Querying Data Process.

the parameters to the API inside the smart contract. At this point, a smart contract transfers data and stores transactions to the distributed ledger of the blockchain network. The default values for parameters sent from the request are intended to minimize errors caused by null fields data.

Fig. 8 presents the process of retrieving data of a particular (e.g., blood and its products). When the user sends a query request to the system, the service query data checks and confirms whether the parameter ID of the blood record was sent or not. Then, the smart contract's APIs are called and passed into the corresponding parameter. Next, the smart contract's APIs check for the existence of data in the request before querying. In the case that the ID does not exist, the smart contract sends an error notification to the user device; otherwise, it returns the data of the blood record corresponding to the requested ID.

## V. Evaluation Scenarios

### A. Environment Setting

Our paradigm is deployed on the Hyperledger Fabric network maintained inside docker containers. In this section, we measure the performance of chaincode in the two scenarios: initializing (i.e., creating data) and accessing data. The experiments are deployed on Ubuntu 20.01 configuration, core i5 2.7Ghz, and 8GB RAM.

To prove the effectiveness of our model, we also define several experiments by exploiting the Hyperledger Caliper[3] that is used to design the test scenarios and collect all the information regarding the performance.

### B. Results

*1) Data Creation:* In this scenario, the study measures the performance of the data initialization function/data created (e.g., blood record) performed through smart contracts. The number of requests sent simultaneously from two users[4]. Table I shows the execution results of the data initialization/creation function (e.g., blood record). The data initialization/creation script is conducted with two users concurrently making 1000 - 10000 requests to the system. We measure the parameters of command success/failure, send rate (transaction per second), system latency (i.e., max, min, avg), and throughput (transaction per second) Based on the execution results in Table I, it

[3]https://www.hyperledger.org/use/caliper

[4]We set up one organization with two users and two peers

TABLE I. Data Creation/Initialization (e.g., Blood Record) Results in the Blood & Product-Chain

| #requests | Succ | Fail | Send Rate (TPS) | Max Latency(s) | Min Latency(s) | Avg Latency(s) | Throughput (TPS) |
|---|---|---|---|---|---|---|---|
| 1000 | 30505 | 18607 | 163.7 | 1251.62 | 1.21 | 780.6 | 31.9 |
| 2000 | 32196 | 18494 | 169 | 1324.05 | 11.62 | 831.13 | 31.3 |
| 3000 | 29776 | 22283 | 173.5 | 1186.66 | 12.63 | 762.59 | 35.2 |
| 4000 | 28269 | 21524 | 165.9 | 1138.24 | 7.24 | 722.93 | 35.1 |
| 5000 | 34362 | 17087 | 171.5 | 1366.83 | 6.85 | 837.88 | 31.5 |
| 6000 | 32828 | 16485 | 164.4 | 1306.1 | 6.29 | 818.69 | 30.8 |
| 7000 | 34831 | 14861 | 165.6 | 1347.43 | 5.6 | 843.07 | 30.3 |
| 8000 | 27970 | 21070 | 163.5 | 1015.16 | 8.1 | 666.99 | 37.4 |
| 9000 | 30158 | 21698 | 172.9 | 1043.7 | 0.92 | 677.78 | 38.8 |
| 10000 | 23672 | 37894 | 205.2 | 840.33 | 6.17 | 600.35 | 54.1 |

TABLE II. Data Access (e.g., Blood Record) Results in the Blood & Product-Chain

| #requests | Succ | Fail | Send Rate (TPS) | Max Latency(s) | Min Latency(s) | Avg Latency(s) | Throughput (TPS) |
|---|---|---|---|---|---|---|---|
| 1000 | 107654 | 5646 | 377.7 | 8.36 | 0.01 | 5.79 | 376.2 |
| 2000 | 108426 | 5639 | 380.2 | 7.9 | 0.01 | 6.1 | 378.8 |
| 3000 | 109370 | 5964 | 384.4 | 8.04 | 0.01 | 6.17 | 382.8 |
| 4000 | 109103 | 5940 | 383.5 | 7.98 | 0.01 | 6.17 | 382 |
| 5000 | 110939 | 5240 | 387.3 | 7.68 | 0.02 | 6.02 | 385.9 |
| 6000 | 110992 | 5452 | 388.1 | 7.86 | 0.01 | 6.08 | 386.9 |
| 7000 | 110769 | 5271 | 386.8 | 7.7 | 0.01 | 6 | 385.2 |
| 8000 | 110329 | 5844 | 387.2 | 8.02 | 0.01 | 6.04 | 385.8 |
| 9000 | 111384 | 5235 | 388.7 | 7.82 | 0.01 | 5.95 | 387.4 |
| 10000 | 85194 | 1643 | 289.5 | 8.09 | 0.01 | 2.89 | 289.1 |

can be seen that the number of successful and failed requests is stable (except in the case of 10000 requests). In the first nine scenarios (1000 - 9000 requests), the number of failed requests ranges from 14861 - 22283, while the number of successful requests is maintained at a much higher rate, from 27970 - 34831 requests. However, in the last scenario, the failure rate is higher than the success rate, 37894 and 23672, respectively. This proves that the system works well with the scenario from 9000 requests (i.e., two users - 2 peers). In addition, we also evaluate the latency of the whole system. Specifically, the maximum delay value ranges from 840.33 to 1366.83 seconds. Besides, the value of send rate ranges from 163.5 to 173.5 (TPS) in the first nine scenarios and the highest in the tenth scenario with 205.2 (TPS). Similarly, throughput measurements ranged from 30.3 to 38.8 (TPS) in the first nine scenarios and reached a maximum value of 54.1 (TPS) in the last one.

*2) Data Access (Retrieving/Querying):* In the second experiment, we consider the data access (e.g., blood record). We also setup 10 scenarios from 1000 to 10000 requests which access the blood record from two users. Table II shows the execution results of the data access function (e.g., blood record). Compared with the first solution, the results of 10 scenarios to evaluate the data accessibility of Blood & Product-Chain are more balanced. Specifically, the successful data retrieval commands rate accounted for 95% (ranging from 85194 to 111384 requests). The system's latency is also minimal, with a maximum of 8.36 seconds and a minimum of 0.01 seconds. The send rate value achieves very high performance from 289.5 to 388.7 (TPS). Similarly, throughput values range from 289.1 to 387.4 (TPS).

### C. Discussion

This is the first attempt to develop a system for the management and storage (i.e., supply chain of blood and its products) of products extracted from blood. Compared to other approaches (see more detail in the related work subject), we aim for adaptability and load-bearing with a large number

of requirements described in scenarios in the data creation and data access sections. Our approach can guarantee a large number of requests (i.e., 10K requests/sec) to initiate and retrieve data.

In future work, we aim to build an authorization mechanism for stakeholders [39], [40]. Specifically, users (e.g., donors) are allowed to design policies to manage their personal data (e.g., what data to share, and with whom). Moreover, this research result is only the first step toward building a system based on blockchain technology in a real environment. We, therefore, aim to implement the proposed model for export in more complex scenarios where healthcare facility processes have multiple roles and execute off-chain (i.e. out of scope for the current version) of medical facilities.

## VI. Conclusion

The paper applies the benefits of Blockchain technology (i.e. transparency, decentralized storage) to propose Blood and Product-Chain: blood and its products transportation management process is based on the limitations of the traditional system. The paper provides a proof of concept based on the Hyperledger Fabric platform, which stores information about blood and blood products during storage and transport. Information is transparently stored for easy verification during transportation and storage. Detailed assessments of the number of successful, and failed requests, latency, send rate (TPS), as well as throughput (TPS), analyzed based on the Hyperledger Caliper platform, proved the feasibility of our approach.

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