ICIC Express Letters
Part B: Applications
Volume **9**, Number **10**, October **2018**

ICIC International ©2018 ISSN 2185-2766
pp. 1067–1073

DESIGN OF AN INNOVATIVE BLOOD COLD CHAIN MANAGEMENT SYSTEM USING BLOCKCHAIN TECHNOLOGIES

Seungeun Kim[1] and Dongsoo Kim[2,*]

[1]Department of IT Distribution and Logistics
[2]Department of Industrial and Information Systems Engineering
Soongsil University
369 Sangdo-Ro, Dongjak-Gu, Seoul 06978, Korea
sungkim@soongsil.ac.kr; *Corresponding author: dskim@ssu.ac.kr

Received March 2018; accepted June 2018

Abstract. *Existing centralized blood management systems have limitations in that they lack detailed blood information and information is not reflected in real time. Also, there is the problem of delayed blood supply in hospitals remote from the blood bank area in the event of an emergency. Blockchain technologies are used in various fields such as finance, electronic voting, power markets, and supply chains. Private type blockchain technologies are relatively fast and reliable, making them suitable for B2B transactions. This paper designs an innovative blood cold chain system using the blockchain technologies. The proposed system helps to ensure information visibility of the whole blood cold chain system and to minimize blood transfer time in special situations.*
Keywords: Blood cold chain, Blockchain, Supply chain management, Information visibility

1. **Introduction.** Blood that is directly linked to human life is highly important because of the specificity of the storage and supply conditions. The blood cold chain defined by WHO (World Health Organization) refers to a system that stores and transports blood at precise temperatures and conditions, from donors to final transfusion sites [10]. Thanks to the peculiarity of blood management, most of them are in charge of the national institutions. In Korea, the Korean Red Cross Blood Service Headquarters established in 1958 is in charge [5]. Fifteen blood banks and three blood inspection centers are operated, and the blood banks collect, store, and distribute the blood.

There are two major issues with the current blood management system. First, the flow of information from collection to consumption or disposal is not clear. Since blood for transfusion does not just stay in the blood banks and it is ultimately used in medical institutions, information such as the amount and reasons of disposal needs to be clearly shared. In a centralized blood cold chain, it is difficult to pinpoint the cause of blood disposal in many medical institutions. Second, since some blood banks under the centralized blood supply system have jurisdiction over a wide area, the transit time may exceed one hour. There are alternatives to adjust the supply area or install the medical institution as a supply area, but there are problems such as institutional interests and responsibility for work [3]. However, given the golden time in emergency situations, the delay in transit time of the blood is critical to the life of the patients, so the existing blood cold chain supply method needs to be improved.

Therefore, this study proposes the blockchain-based blood cold chain system design. In the blood supply process with difficult storage and transportation conditions, the blockchain technologies can generate traceability by generating a single record for each point. Existing blood management systems report only the amount of blood collection,

DOI: 10.24507/icicelb.09.10.1067

production, and storage mistakes that occur at the blood service headquarters. It is expected that the blockchain will be able to identify management problems of the entire blood cold chain participants due to the inability to counterfeit or tamper with information. Next, the innovative system proposes blood transactions between medical institutions to cope with suddenly increased demands of a specific region or a medical institution in emergency situations. By designing the situation for requesting and responding to the blood from the surrounding medical institutions, it will help stable blood supply even in special situations.

The rest of the paper is organized as follows. Section 2 reviews previous researches of blockchain and blood cold chain system. Section 3 presents the design of new blood cold chain system and Section 4 discusses benefits of the new system and requirements of the implementation. Finally, Section 5 offers conclusions and describes future work.

2. **Related Work.** This chapter discusses previous studies related to blockchain and blood cold chain system. Blockchain is a state sharing and consensus-building technique that fulfills transaction record retention and synchronization of distributed network participant systems [4]. With no centralized server, transaction records are recorded and shared on the distributed ledger. When a new transaction is generated, it is organized into units of blocks. The blockchain structure is a format of block sets concatenated successively. Blockchain can be classified into three types: public, private, and consortium. Base technologies include Bitcoin Core, Ethereum, Hyperledger Fabric, etc. The Hyperledger Fabric is characterized as being suitable for B2B transactions, and its membership services can limit the entry of unauthorized participants [2]. In addition, there are nodes for verifying the transactions during transaction processing, so that it is possible to remove the uncertain transactions early and is relatively fast. Because of these advantages, we aim to design a Hyperledger Fabric architecture based system.

Blockchain is expected to improve visibility of product supply chain and streamline work among participants through real time tracking capability and smart contractbased characteristics. One of blockchain based supply chain projects is that China's Walmart and IBM affiliated in 2016, aimed at securing consumer confidence in food safety [7]. It is for applying food safety of pork, which allows consumers to identify production sites, slaughter and distribution processes. From Walmart's point of view, quality control is facilitated as food details can be tracked immediately. Another project, the Counterfeit Medicines Project, is one of the projects in the Hyperledger Research Network, which displays a timestamp for each drug to prevent the production of counterfeit medicines [6]. Blockchain can be used to track and identify cases of forgery, quality degradation, and theft by tracking drug production times and locations and clarifying their sources. In the field of medicine, blockchain contributes to increased safety and reduced costs relating medical sectors. Within the supply chain, drug safety is ensured by identifying changes in ownership of drugs between manufacturers, distributors, packers, and end users.

On the other hand, researches on the blood cold chain system have been conducted by several approaches. Davis et al. proposed RFID based dynamic blood information management system [8]. They pointed out the problems of the existing blood information management system, for example, the amount of information that can be contained in the bar code is limited, and the information is not reflected in the blood source in real time. Jabbarzadeh et al. proposed a network for blood supply chain in the event of a disaster using real data [1]. Kim et al. proposed a modified model that minimizes transportation time by designating specific hospitals as blood distribution institutions [9].

The existing blood information management system manages the information just focusing on the situations before it is supplied from blood banks to a number of medical institutions. Despite efforts to track real-time information on the blood boxes or transport vehicles, there is a limitation to how closely each medical institution conducts blood transfusions and disposal. Besides, in the event of an emergency, there is a possibility that placing temporary facilities or designating a new base for blood supply, does not take realistic complex factors into account.

This study overcomes the limitations of existing research and methods in terms of information visibility in blood information systems and blood supply time during emergencies. The new system can secure the transparency of blood information management by using real-time information recording and security superiority of blockchain technology. It is important to know how the blood for transfusions is used in the final consumer site. Considering this point, this system has the advantages of clarifying the status of blood disposal by ensuring the information visibility of each hospital unit. In terms of blood supply time during emergencies, blood supply time can be shortened by proposing a B2B transaction in which blood is directly transferred between hospitals. Requesting blood for hospitals, closer to the blood banks when an emergency occurs does not incur the cost of building new blood banks and can prevent liability issues that might arise by designating certain hospitals as distribution points.

In addition, the blockchain is actively studied in the supply chain and healthcare sectors. This study contributes to further expanding the scope of researches by applying it to the field of blood supply chain, which has not yet been covered by blockchain technologies.

3. **Design of Blood Cold Chain System.** Since this paper proposes a private type blockchain system, access to the system is possible only for blood cold chain participants. These include the blood service headquarter, blood banks, inspection centers, transport vehicles, and hospitals. In this study, two situations are designed. First, it is situation that blood suitable for transfusion is consumed in hospitals. Second, it is situation that blood cannot be supplied from the blood banks to the hospitals in golden time.

Blood for transfusion needs to be accompanied by quality assurance from the blood donors to the recipients. Therefore, end-to-end visibility of the blood cold chain is required. Figure 1 shows the existing blood cold chain and the proposed new system. The left side of the figure is a centralized structure with the existing blood cold chain system, and the right side is the system with the proposed shared ledger technologies.

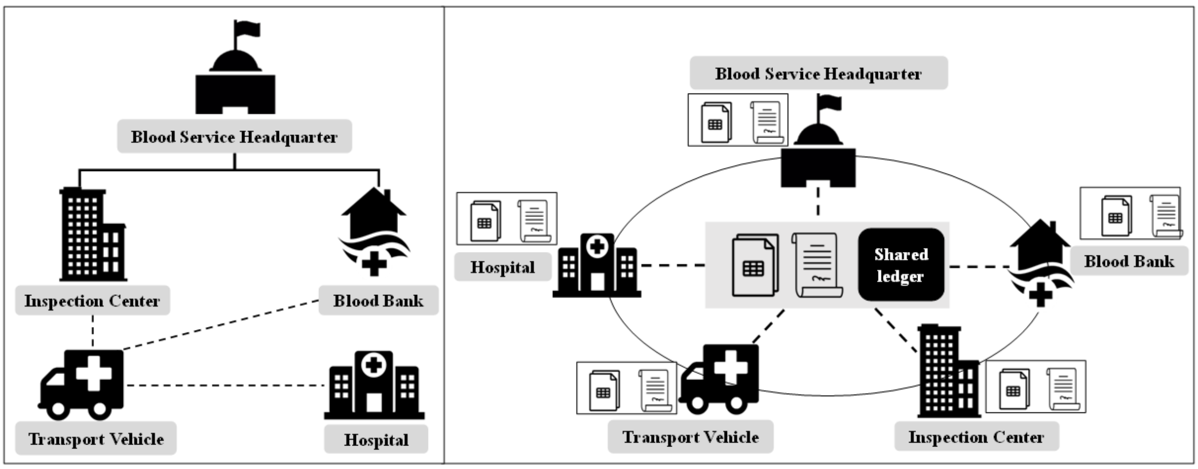

Figure 1. Conceptual architecture of blood cold chain system

Figure 2 shows the distributed ledger structure where all transactions are recorded and shared within the blood cold chain network. The collected transfusion blood information generation transaction is in Block 1000, and the transaction that moves from the blood bank to the inspection center through the transport vehicle exists in Block 1001 and Block 1002. In Block 1003 and Block 1004, there are transactions in which the blood that has been judged as conforming moves to the blood bank again. Block 1005 to Block 1007

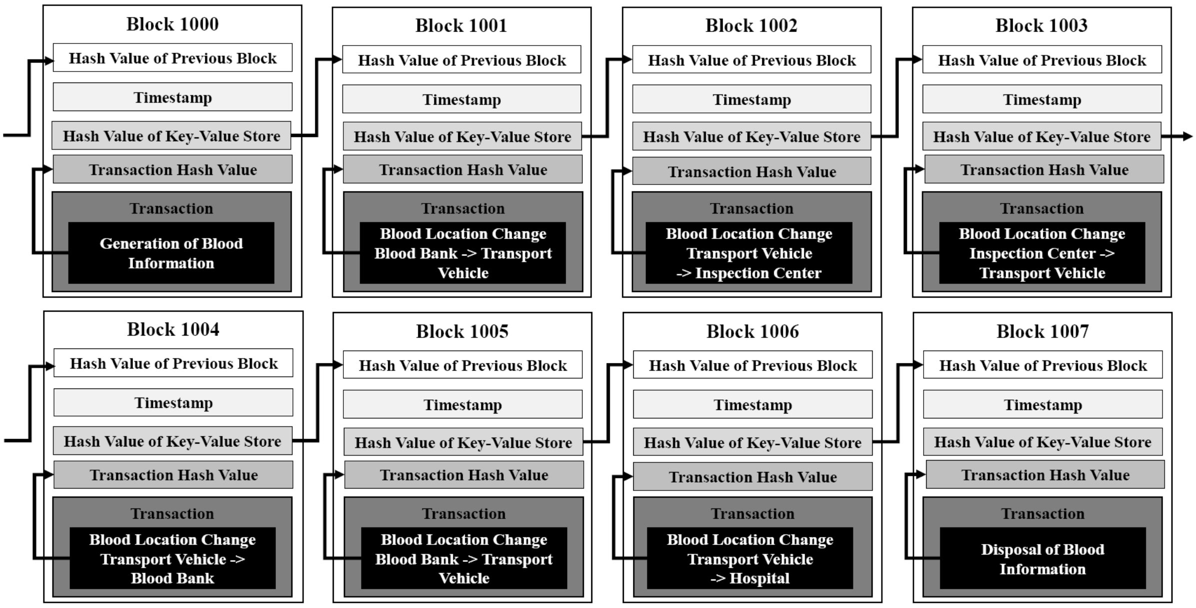

FIGURE 2. Architecture of the shared ledger

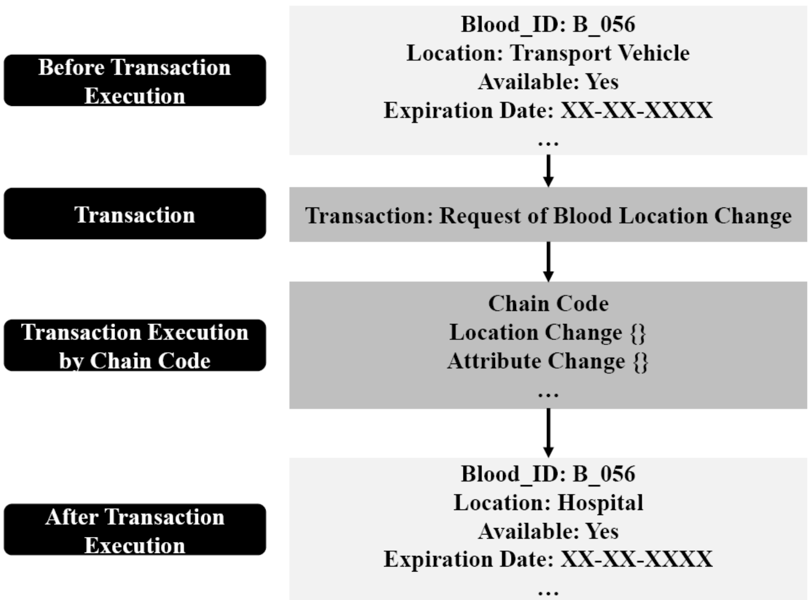

FIGURE 3. Example of performing the transaction

indicate that transactions have occurred in which the blood is transferred to the hospital upon request of the hospital and the blood information is finally discarded. Processing of the smart contract like this, the invoked transactions are recorded like logs.

Because it is designed based on a Hyperledger Fabric architecture, there is a key-value store (KVS) in Figure 2, unlike Bitcoin Core or Ethereum [2]. This ensures the latest state by preserving the transaction processing results. For example, in Block 1001, if the blood location has changed from the blood bank to the transport vehicle, results are recorded in KVS that blood is in the transport vehicle not the blood bank. All verification nodes have the same KVS, and the hash value is recorded in the blockchain. In this system, KVS can be said to be a place where the status of blood changes is managed.

Meanwhile, the chain code is a transaction execution processing program and is held by all the validation nodes [2]. Figure 3 shows one transaction requesting a change of location from the transport vehicle to the hospital. It shows that the location has changed in the processing result data. After the transaction request and execution, it can be seen that the location value has changed from the transport vehicle to the hospital. On the other hand, the expiration date indicates the date when the blood can be used. In addition to this, the information such as the amount of blood and the type of blood can belong to attribute.

Since quick supply of blood in golden time is an important issue, we proposed a system to supply blood directly between hospitals. This is when blood is not supplied from the blood banks to the hospitals within the golden time, and the surplus blood is requested from the nearby hospitals. The transaction flow for that scenario is shown in Figure 4. The Hospital A is asking for the surplus blood of the Hospital B, and it goes through a consensus process that the request is valid.

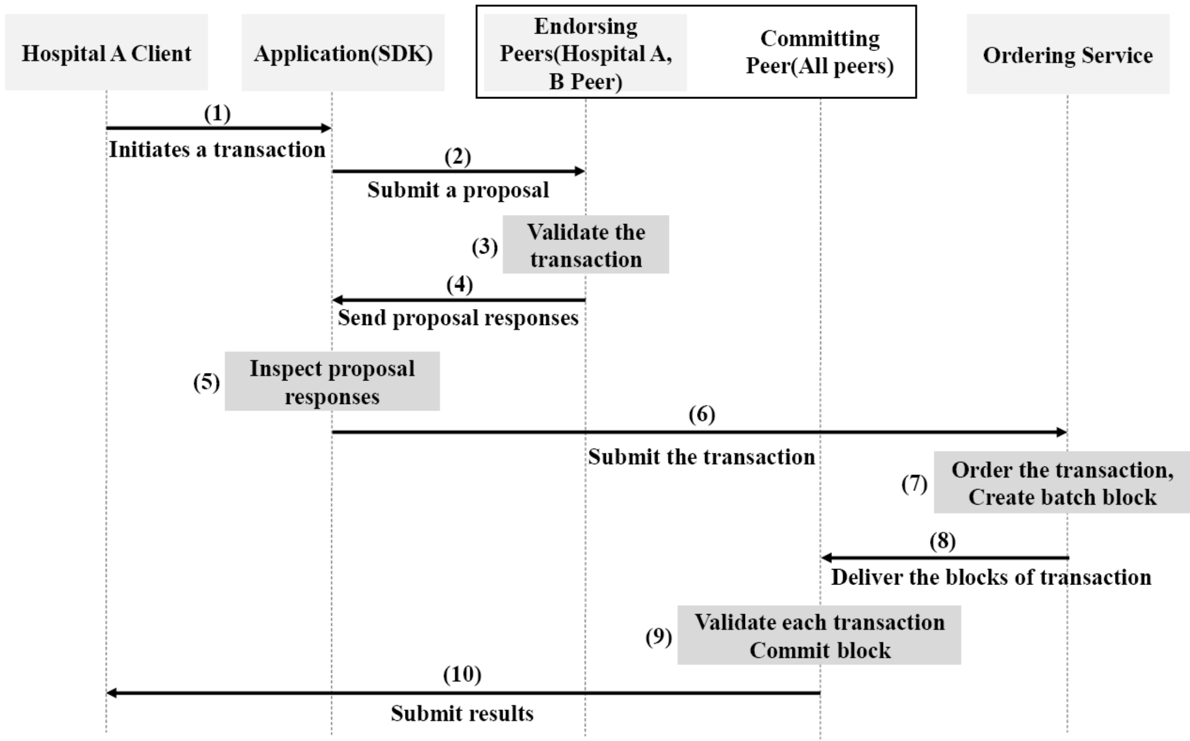

Figure 4. Transaction and consensus flow

In the blockchain, the consensus process is a mechanism to ensure that all participants have consistent ledgers [2]. All participants should agree on the order of transactions and transactions, and keep synchronizing the state of the verification nodes to maintain the same ledger. In the case of Hyperledger Fabric, it uses a distributed consensus algorithm by specific verification nodes.

In this case, the client of Hospital A requests a transaction that blood is needed (labeled (1) in Figure 4). The proposal is delivered to the endorsing peers (labeled (2)). The peers of Hospitals A and B corresponding to the endorsing peers execute the chain code to verify the transaction (labeled (3)). The application checks the results received from the peers of Hospitals A and B (labeled (4), (5)). The application submits the transaction to the Ordering Service (labeled (6)). The Ordering Service defines a transaction sequence, creates a block and sends it to all peers (labeled (7), (8)). Each peer validates the transaction, confirms that it satisfies the endorsement conditions, and then commits the transaction (labeled (9)). Finally, the transaction is made to give blood to the Hospital A from the Hospital B.

4. **Discussions.** This section presents the key benefits of the proposed system and the requirements for system implementation. The benefits can be explained in terms of the

two situations discussed in Section 3. In the first situation, we can confirm that the blood information is recorded at each supply point through the distributed ledger structure and the transaction flow. This complements the information limitations of existing centralized blood information system, ensuring the information visibility of the entire blood cold chain. In a second situation, the new system that reduces transportation time through blood B2B transactions in emergency situations can be identified. The transactions can be performed by a consensus algorithm to ensure reliability. While establishing a new base for supplying blood does not address uncertainty about where urgent blood demand may arise, the proposed system can overcome the limitations by asking hospitals that are near range.

This paper presents the design of the new blood supply process based on the Hyperledger Fabric technologies. There are several requirements to consider for system implementation. Before implementation, it is needed to complete the business logic setup for the blood supply and the detailed data structure design of the blocks to be distributed to the information system. After development PCs are set up, installation and operation of Hyperledger Fabric are necessary and development of chain code for transaction execution is required. Besides, work that is linking between existing blood information management system and new system will be needed. After the demonstration scenario is set up, the verification results are obtained accordingly. After that, it continues to work on complementing the system to make sure it works according to the business logic.

5. **Conclusions.** In this paper, we proposed the innovative blood cold chain system using blockchain technologies. We presented the distributed ledger structure and transaction execution process of the situation where the collected blood reaches the final hospitals. Existing centralized blood management system does not provide detailed information on blood usage or disposal in the final many medical institutions. In this respect, the blockchain technologies offer the possibility to maintain a transparent blood management system, especially since data cannot be counterfeited and tampered with. In addition, the paper showed blood contracts between hospitals in the event of emergencies through the transaction and consensus flows. This approach is to allow hospitals that are far from the blood banks to facilitate blood supply in emergency situations. Since blood has a certain storage period, it is expected that it will be possible to increase the blood utilization rate by using surplus blood for the supply. Meanwhile, this study contributes to coverage of blockchain technologies in healthcare by applying to the blood cold chain system.

In the future, the researchers will expand the scope of this study by dealing with events such as inspection failure, storage errors, and disposals. We also hope to implement the proposed design using the Hyperledger Fabric technique tools.

Acknowledgment. This work was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2017R1D1A1B05029080). The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

REFERENCES

[1] A. Jabbarzadeh, F. Behnam and S. Stefan, Dynamic supply chain network design for the supply of blood in disasters: A robust model with real world application, *Transportation Research Part E: Logistics and Transportation Review*, vol.70, pp.225-244, 2014.
[2] A. Yoshiharu et al., *Blockchain Structure and Theory*, Wikibooks, 2017.
[3] C. Kim and S. Paek, A study on the factor of supply chain management success on blood supply chain, *The Journal of Internet Electronic Commerce Research*, vol.8, no.4, pp.237-259, 2008.
[4] C. Michael et al., Blockchain technology: Beyond bitcoin, *Applied Innovation*, pp.6-10, 2016.
[5] *Korean Red Cross Blood Service Headquarters*, https://www.bloodinfo.net/main.do.

[6] M. Mettler, Blockchain technology in healthcare: The revolution starts here, *IEEE the 18th International Conference on e-Health Networking, Applications and Services (Healthcom)*, pp.1-3, 2016.

[7] N. Hackius and M. Petersen, Blockchain in logistics and supply chain: Trick or treat?, *Proc. of the Hamburg International Conference of Logistics (HICL)*, pp.3-18, 2017.

[8] R. Davis et al., Tracking blood products in blood centres using radio frequency identification: A comprehensive assessment, *Vox Sanguinis*, vol.91, no.1, pp.50-60, 2009.

[9] S. Kim, J. Kim, H. Kim and B. Chung, Agile blood supply chain design considering golden time, *Korean Journal of Logistics*, vol.24, no.4, pp.27-40, 2016.

[10] *The Blood Cold Chain*, World Health Organization, http://www.who.int/bloodsafety/processing/who_eht_11_04_en.pdf?ua=1.