DOKUZ EYLÜL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

FOOD SUPPLY CHAIN TRACEABILITY ARCHTICETURE BASED ON BLOCKCHAIN TECHNOLOGY

by

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October, 2021

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A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfilment of the Requirements for the Degree of Master of Science in Computer Engineering

by
Burak KÖSE

October, 2021
İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"FOOD SUPPLY CHAIN TRACEABILITY ARCHITECTURE BASED ON BLOCKCHAIN TECHNOLOGY"** completed by **BURAK KÖSE** under supervision of **ASSOC. PROF. DR. SEMİH UTKU** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ACKNOWLEDGEMENTS

I would like to thank my esteemed advisor Assoc. Prof. Dr. Semih UTKU, who shared his valuable knowledge with us and supported us in every issue for two years. Also I would like to thank Aslı BAHÇE, who guided me and exchanged ideas throughout the study.

Burak KÖSE

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ABSTRACT

Nutrition is one of our most important needs. The nutritional needs of societies are provided by food supply chains. Transparency and traceability of food supply chains are very important, because foods are a factor affecting human health. There are many known problems in today's food supply chains, such as food fraud. Popular and emerging blockchain technology is an effective tool that can be used to eliminate these problems. In this study, a blockchain supply chain system is designed by using Hyperledger Fabric platform. On the other hand, how the blockchain solutions overcome to these problems are examined. Different blockchain types and platforms are compared. Obtained results show that Hyperledger Fabric is a suitable and effective platform to solve food supply chain problems. An exemplary system is designed and developed with Fabric.

Keywords: Food supply chains, food traceability, blockchain, Hyperledger Fabric.

BLOCKCHAIN TEKNOLOJİSİNE DAYALI GIDA TEDARİK ZİNCİRİ İZLENEBİLİRLİK MİMARİSİ

ÖZ

Beslenme en önemli ihtiyaçlarımızdan biridir. Toplumların beslenme ihtiyaçları gıda tedarik zincirleri tarafından sağlanmaktadır. Gıda tedarik zincirlerinin şeffaflığı ve izlenebilirliği çok önemlidir çünkü gıdalar insan sağlığını etkileyen bir faktördür. Günümüz gıda tedarik zincirlerinde gıda sahtekarlığı gibi bilinen birçok sorun bulunmaktadır. Popüler ve gelişmekte olan blockchain teknolojisi, bu sorunları ortadan kaldırmak için kullanılabilecek etkili bir araçtır. Bu çalışmada, Hyperledger Fabric platformu kullanılarak bir blockchain tedarik zinciri sistemi tasarlanmıştır. Öte yandan blockchain çözümlerinin bu sorunları nasıl aştığı incelenmektedir. Farklı blockchain türleri ve platformları karşılaştırılır. Elde edilen sonuçlar, Hyperledger Fabric'in gıda tedarik zinciri problemlerini çözmek için uygun ve etkili bir platform olduğunu göstermektedir. Fabric ile örnek bir sistem tasarlandı ve geliştirildi.

Anahtar kelimeler: Besin tedarik zincirleri, gıda izlenilebilirliği, blok zinciri, Hyperledger Fabric.

CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1
INTRODUCTION

One of the most striking features of the blockchain is that the transactions performed in a blockchain system do not need a centralized structure and that the data is kept immutable. The blockchain network has a fully distributed architecture, thus avoiding single point failure, which is the biggest problem of central systems. The main problem of distributed systems such as blockchain is how to achieve the reliability of the overall system despite the existence of erroneous transactions. If any node in the network fails, other nodes in the system should not be affected and the system should continue to run. The consensus mechanism, which is the fault-tolerance mechanism, is used for this. In this way, it is ensured that the data in the system remains secure and the nodes work together. Although there has been a lot of research and work on solving the problems of food supply chains with blockchain, there is little experience in implementing blockchain in real-world software applications.

After the discovery of the Bitcoin currency, blockchain technology attracted attention. Blockchain has proven that it can produce solutions to many problems with its fully distributed architecture and immutable data structure.

Nowadays, although it is on the agenda with crypto currencies, it is important candidate for produce solutions on many different fields such as financial services, reputation systems, internet of things and supply chains thanks to the innovative features it brings with it.

In this study, we examined blockchain-based studies on food supply chains. Blockchain platforms differ according to their types and architectures in terms of many features such as access and transaction costs. For this reason, we investigated blockchain types and platforms. As a result of our research, we decided to use Hyperledger Fabric. We explain why we chose fabric. With fabric, we share the system we developed and the challenges we face.

1.1 Problem Definition

Nutrition is one of the basic needs of people. With the increasing population, the problem of meeting the food needs emerging worldwide emphasizes the importance of food supply chains. The food supply chain covers the entire process from the production of the food to its consumption.

Food quality and reliability are the most critical features of this chain. Food is one of the factors affecting consumer health. The management of food safety risks generally focuses on the dangers that occur naturally or unintentionally in food production and supply processes. However, deliberate behaviour in the production process to gain economic profit causes serious quality and safety problems (Tähkäpää et al., 2015).

Although food fraud seems to be the problem of today, it is a very old problem. This topic has historically been studied by considering real events on different products. As a result of the examinations, it was found that the resources provided for the application of science and the inspections performed were insufficient (Shears, 2010). The sanctions of authorities against fraudulent and fraudulent actors will ensure that the food supply chain is as safe as possible.

Supply chains must be fully traceable to ensure food quality. However, due to the natural nature of the supply chain, it is difficult to ensure full traceability. The supply chain consists of many stakeholders. To monitor a product along its entire supply chain, all stakeholders in the chain must implement traceability solutions. The weak communication between stakeholders is one of the important problems of the supply chain. A comprehensive review has been made on cooperation in the supply chain, a significant number of cooperation elements have been identified, and studies have been made on the performance and efficiency of cooperation on the supply chain (Coveney, 2008). All collaborators in the supply chain need to be in cooperation. Traceability will increase communication and trust not only among consumers but also among stakeholders. It will also ensure that the intervention of unknown and uncontrolled third parties in the process is avoided.

Today, with the development of technology and the increase of consumer awareness, food quality and reliability have become very important for consumers. The coverage of many food scandals in the news and diseases caused by foods that could harm consumer health have reduced confidence of consumers in food production and supply chains (Barratt, 2004).

1.2 Blockchain Solves Problems of Food Supply Chains

To eliminate the problems mentioned above, full traceability and transparency of food supply chains should be ensured. In this way, a quality and reliable food production and supply environment is created that does not risk consumer health. With the rapid development of technology, many technologies have been applied on the traceability of supply chains. Most of these applied technologies and studies have adopted the centralized architecture. Centralized systems bring some problems with them. Single point failure is one of the most important known deficiencies of these systems. In addition, since identity management is managed by a single organization, it offers a monopolistic approach to problems such as fraud and fraud. Since the supply chain consists of multiple stakeholders, centralized systems are insufficient to solve the problems of the complex process. Blockchain technology has become an effective tool for solving these problems with its underlying distributed architecture and many features. In addition, keeping data immutable in the blockchain system brings transparency and reliability. Thanks to these features, it has created a lot of excitement about solving problems in food supply chains and has become the focus of many researchers.

1.3 Hyperledger Fabric is Appropriate for Solution

Hyperledger Fabric is designed modularly. Components such as consensus and subscription services are used as plug and play. Modularity allows to choose the consensus mechanism to be used. In this way, it offers solutions not only to financial services but also to many areas. While providing privacy with its network structure, it also provides a solution that is scalable in terms of performance. Also, all previous blockchain systems have taken the order-execution architecture as the basis. The order-execute architecture limits scalability, requiring transactions to be executed sequentially and approved by all peers. Fabric offers us different architecture and follows execute-order-validate architecture instead of standard order-execute architecture. With this architecture, it overcomes some problems such as resource consumption (Androulaki et al., 2018). In addition, the fabric network allows multiple different organizations, channels, and smart contracts. Considering its structure and properties, we advocate that Hyperledger fabric is a suitable and effective platform to solve the problems of food supply chains.

1.4 Outline

The thesis is organized as follows. The literature review is presented in Chapter 2. A briefly description of the blockchain, its types and platforms, and a comparison of its platforms and types are in Chapter 3. The reason why blockchain is an effective tool for solving food supply chain problems and why the Hyperledger Fabric platform is used when developing system is explained in Chapter 4. The architecture of the application developed with Fabric is detailed in Chapter 5. The conclusion of the article and the difficulties encountered are described in Chapter 6. It is given in Future works Chapter 7.

CHAPTER 2
RELATED WORKS

In recent years, many studies have been done on blockchain technology. In 2017, Zheng, et al. have thoroughly studied the blockchain technology. In the study, consensus algorithms are explained and compared in detail. In addition, the technical difficulties of these algorithms are also included in the article. In the study, it was aimed to determine future study areas for blockchain (Zheng et al., 2017).

Yang, et al. In their study, they proposed a new blockchain-based system to solve the existing privacy issues in crowdsensing systems. It was want-ed to benefit from the innovations brought by the blockchain for distributed architecture and privacy. According to the results of the study, it is observed that the system performs well in the protection of ground privacy (Yang et al., 2019).

Yuan, et al. in their study, they mentioned the problem of granting untrust-ed trade emission permission in the central trade system. In the study, it was aimed to develop a blockchain based system to solve the problems of centralized systems (Yuan et al., 2019).

In 2019, Wei Feng, et al. In their study, MCS has developed a Blockchain based MCS system called MCS-Chain to perform a fully decentralized and de-centralized trust management in MCS. A new consensus mechanism has been created, which aims to increase the low efficiency of traditional block chain technology, greatly reducing the computational burden for block building. With this study, single point error of centralized systems was avoided. The application developed for Android and Windows has proven the security it provides on these platforms. However, privacy has not been addressed in this study (Feng & Yan, 2019).

A common solution to avoid the disadvantages of the blockchain was investigated by Lin, et al. A food safety traceability system based on blockchain, and EPC Information Services was proposed. As a result of the study, it has been observed that it performs better than current mainstream systems in terms of traceability, tamper resistance, decentralization degree, amount of in-chain data (Lin et al., 2019).

Košt’ál, et al. in their study have worked on a new network monitoring and management architecture based on blockchain technology. In the study, it was desired to increase the efficiency and safety of IoT devices. The basic innovation of the solution is the management of the IoT devices' configuration files in corporate networks using a block chain using a block chain (Košťál et al., 2019).

Blockchain offers solutions to many areas. It is an important candidate for solving food supply chain problems. A lot of work has been done to solve these problems. Most of the systems developed to solve the problems of food supply chains have a centralized architecture. Due to this structure, current supply chains operate linearly from the production process to the consumers. Data are centralized in each stakeholder of the supply chain. One stakeholder cannot see actions from other items. This causes the source of the food to be unverifiable. Since each stakeholder keeps the data in its own system, it cannot be ensured that the data are reliable (Casado-Vara et al., 2018). Blockchain, along with its fully distributed architecture, is the most important candidate for solving these problems. Many studies have been carried out to measure the applicability of blockchain to food supply chains. Nevertheless, these researches cover a small part of the research on blockchain (Dujak & Sajter, 2019). Jiang Duan et al conducted extensive research based on content analysis to measure the acceptance of Blockchain technology for the supply chains on food (Duan et al., 2020). Most researches show that blockchain technology has advantages and disadvantages due to its nature. Benefits and challenges of blockchain are shown in table 2.1.

Table 2.1 Benefits and challenges of blockchain

Benefits	**Challenges**
Traceability	Lack of understanding
Transparency	Immature technology
Reliability	Participant corporation
Sustainability	Trade secrets
Efficiency	Raw data manipulation

Food supply chains consist of many stakeholders. Blockchain provides transparency for all actors. Data is stored as irreversibly in blockchain. This creates a unique level of reliability that accommodates with a more retainable industry. Blockchain helps collaborating actors to consolidate their communication with existing customers and draw the attention of new ones (Galvez et al., 2018). Hackius and Petersen worked on the online survey. In this study, they identified logistics experts as the target group. With the survey they conducted, they researched the obstacles in supply chains and asked the experts about their expectations from blockchain technology. As a result of this field research, they found that the participants responded positively blockchain which brings solutions with new features (Hackius & Petersen, 2017).

HACCP (Hazard Analysis and Critical Control Points) is a systematic approach that focuses on food safety in detail and prevents dangers that will threaten human health. The main purpose of the standard is to make food production and consumption the healthiest. Therefore, it prioritizes social welfare and hygienic requirements (Mortimore & Wallace, 2013). Feng Tian created a food supply chain traceability system that could provide an open information platform for all supply chain members for real-time food tracking based on HACCP, blockchain and Internet of Things. With a scenario, they examined the system from all angles. They proposed that it would provide all supply chain members with real-time information on the safety status of food products, greatly reducing the risk of centralized information systems and making them more secure, distributed, transparent and collaborative. They argued that system could significantly increase the efficiency and transparency of the food supply chain, which would obviously increase food security and rebuild consumer confidence in the food industry (Tian, 2018).

With the development of technology, much progress has been made in the field of IoT. Thanks to this, the use of IoT in food supply chains has increased. However, existing IoT-based traceability and provenance systems are built on centralized infrastructure. To get rid of the problems caused by this structure, Pincheira Caro et al developed the blockchain-based AgriBlockIoT product in their study. They defined the model they created within a specific field system. They installed two different blockchain applications on this area, Ethereum and Hyperledger Sawtooth. They evaluated 2 applications in terms of performance, latency, CPU, and network usage. As a result of their analysis, they concluded that the Hyperledger Sawtooth-based application performed better in terms of metrics compared to the Ethereum-based application. But in line with the needs, they stated that Ethereum's software maturity is high, more participatory, scalable, and reliable, so performance can be ignored. They emphasized that IoT devices have processing power due to their small size, and they said that Hyperledger sawtooth could be a better solution at this point (Caro et al., 2018).

Although blockchain technology is evolving, it is underutilized in existing software applications. Therefore, we have little experience with the application of this technology. Xiwei Xu et al developed the blockchain system called OriginChain. In a system using a central database, they removed the central database and used blockchain instead. With this change, they restructured the system. At the design phase of blockchain, they applied the blockchain approach recommended by the software architecture community. They compared the read-write performances of the Ethereum-based blockchain application they established with the local and remote database. As a result of their analysis, they found that every node has a copy of the block chain, so there is no performance loss in reading transactions. However, due to the consensus process, they observed that the writes were very slow compared to local and remote databases (Xu et al., 2019).

Works on food supply chains is limited by most of his theoretical applications and unstructured experiences. Blockchain types and platforms have different advantages and disadvantages. Considering the needs of the field, these should be examined and the platform that will be the right solution for the need should be worked on. This article examines blockchain types and platforms. The blockchain platform to be used was decided and a sample application was developed.

CHAPTER 3
BLOCKCHAIN

3.1 What is Blockchain?

Blockchain is a database. Traditional databases can be accessed by users with permission, and they can filter and manipulate data. Blockchain differs from these at this point. Depending on the blockchain types, the user group accessing the data may vary, but the data cannot be manipulated. Blockchain can be defined as an immutable list of data. It consists of blocks. When data is added to block, it cannot be changed later. Each block is connected to the previous block by cryptographic key. Thanks to this, the blockchain can be traced, but it cannot be broken.

3.2 Structure of Blockchain

Blockchain consists of blocks that are sequentially connected to each other. Transactions are stored in these blocks. The blocks that make up the blockchain consist of 2 parts, the header, and the body. The structure of block is indicated in figure 2.1.

The block header consists of 6 parameters. These are version, previous hash, difficulty, timestamp, nonce, and Merkle root hash. Version specifies the software and protocol version on the blockchain. In this way, updates in the blockchain can be tracked. The previous hash is the 256-bit Merkle root hash of the previous block. Difficulty also is called nBits, is a unit of measure indicates that how difficult it is to find a hash under a given target. Timestamp indicates the creation time of the block. It is an approximate value and is stored as seconds from Unix Epoch. Nonce (number only used once), the random value used when calculating the hash value of the block. Miners must find this value to solve the block. The Merkle root hash is the hash value generated from all transactions in the block.

The block body is composed of a transaction counter and transactions. The maximum number of transactions that a block can contain depends on the block size and the size of each transaction (Zheng et al., 2017). Size of data to be stored in blocks can be customized. For example, the number of items in the block can be limited or the block size limited. It depends on the design of the blockchain.

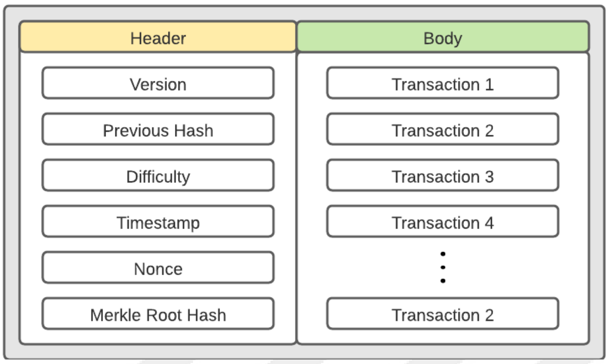

Figure 2.1 Structure of block

3.3 Types of Blockchain

The main purpose of the blockchain is to carry out the transactions and the information exchange between the nodes over a secure network and keep them unchangeable. Blockchains differ due to the structure and configurations they use while achieving this goal. There are 2 different block chains, public and private.

3.3.1 Public Blockchain

Anyone with internet access can join the public blockchain. There are no restrictions. All stakeholders participating in the network can access the records available on the network (Guegan, 2017). They are also authorized to mining or verify transactions. Each authorized node has a copy of the blockchain data. This makes the entire system completely open and transparent. It is safe because it has a completely distributed infrastructure. Since it is a large network of many nodes, the number of transactions per second is low. For this reason, its scalability decreases (Chauhan et al., 2018). Proof of work is used to ensure trust, as it is made up of completely anonymous nodes. Although providing anonymity is an advantage, the time and energy required for proof of work is a disadvantage.

3.3.2 Private Blockchain

The private block chain is only accessible to verified participants. Only stakeholders can access the records on the network. Proof of work is not needed as all participants are verified when joining the network. It also saves time and energy expenditure. For this reason, the number of transactions per second is high and the scalability of these networks is high (Pongnumkul et al., 2017). There are designated permissions to perform certain activities on the network. This indicates the role meaning for the participants. The roles of the participants and their roles in the network may be different. Identity management can be centralized, because of participation process in the network is managed by the organization. The occurrence of such a situation adversely affects security.

3.3.3 Comparison of Public and Private Blockchain

Public and private blockchains were compared in 3 different contexts. These are characteristics, advantages, and disadvantages. Comparison of blockchain types is given in table 3.1.

Table 3.1 The comparison of public and private blockchain

	Public Blockchain	**Private Blockchain**
Characteristics	Truly decentralized, Anonymity, Transparency, Immutable, Enhanced security	Vary decentralization, Governance, Customizability, Efficiency, Anonymity, Transparency
Advantages	Open to everyone, Bring trust to users, Offers high security	Extremely fast output, Scalable network, Offers energy efficiency
Disadvantages	Slow transactions, Harder to scale, Not energy efficient	Not truly decentralized, Less transparent, Partial immutability

3.4 Consensus Mechanisms

The most important point of blockchains is the consensus mechanism. These mechanisms are used to come to a consensus about all the operations taking place on the network and the current state of the system. There are 3 commonly known consensus mechanisms. These are proof of work, proof of stake and practical byzantine fault tolerance.

3.4.1 Proof of Work (PoW)

Mining is required to validate a new process. Miners solve a difficult problem and verify the process by performing this excavation. This mechanism is a system in which miners holding most of the processing power have more say in the network and therefore gain more returns (Baliga, 2017; Panda et al., 2019). As an example, Bitcoin and Ethereum use this mechanism.

3.4.2 Proof of Stake (PoS)

Users who want to be able to verify a new transaction and get a share of the revenue must lock their cryptocurrency assets to be used for verification. In this locking process, which is called "staking" (getting a share from the income), the amount to be used for this transaction in the wallet cannot be withdrawn from the wallet until it is unlocked and is marked as the user's share on the network (Baliga, 2017; Panda et al., 2019).

3.4.3 Practical Byzantine Fault Tolerance (pBFT)

In networks with distributed architecture, some nodes may fail or be malicious. The ability to reach consensus even when faced with such a situation is called BFT. It is derived from the Problem of Byzantine Generals. For a new transaction to be included in the ledger, at least 2/3 of the approved spouses must give the same response. It is especially used in permissioned blockchains (Baliga, 2017).

3.4.4 Comparison of Consensus Mechanisms

Consensus mechanisms are examined under 4 different headings. These are blockchain type, transaction rate, energy consumption, and trust model. Comparison of consensus mechanisms is given in table 3.2.

Table 3.2 The comparison of PoW, PoS, and pBFT

	PoW	**PoS**	**pBFT**
Blockchain Type	Permissionless	Both	Permissioned
Transaction Rate	Low	High	High
Energy Consumption	High	Low	Low
Trust Model	Untrusted	Untrusted	Semi-trusted

3.5 Blockchain Platforms

Blockchain platforms show different features according to their purposes. Each platform has advantages and disadvantages. In this article, 3 different blockchain platforms are examined and compared. These are Bitcoin, Ethereum, and Hyperledger Fabric.

3.5.1 Bitcoin

Bitcoin is a cryptocurrency published by Satoshi Nakamoto in 2008. It is not known today by whom or by whom it was developed. They enabled peer-to-peer money transfers without the need for any centralized structure. Each peer is part of the distributed network. Proof-of-work consensus mechanism is used to verify transactions by peers. In this way, there is no need for a third party in transactions (Nakamoto, 2008).

Bitcoin is public. Anyone can join the network. Network scalability is high. They require a lot of processing power as they use the proof-of-work consensus mechanism. For this reason, the energy required for mining is high.

3.5.2 Ethereum

Ethereum is the blockchain platform that provides the currency to be used in applications built on the blockchain. It is not created for the crypto currency system. Ethereum is essentially the same as any other blockchain. It is an immutable database.

The innovative approach in Ethereum is smart contracts. Smart contracts are developed with its own programming language, Solidity. In this way, it allows the development of different programs on the network. The main purpose of Ethereum is to facilitate the functioning of decentralized applications developed with smart contracts.

Anyone can join the Ethereum blockchain network. It uses the proof-of-stake consensus mechanism. In this way, it has reduced the energy requirement and time required for mining.

3.5.3 Hyperledger Fabric

Hyperledger Fabric is the blockchain framework for the Hyperledger platform built to develop solutions and applications to be used in private businesses. It has a modular structure thanks to the use of plug and play components, it is designed to produce corporate solutions.

Hyperledger Fabric is a private blockchain. Only approved peers can join the network. For this reason, the number of nodes in the network is less than public blockchains. In this way, transactions on the network can be accelerated.

3.5.4 Comparison of Blockchain Platforms

There is an inverse proportion between performance and scalability in blockchains. Performance decreases as scalability increases. Scalability and security are at the forefront in public blockchains. For this reason, the number of transactions per second is low. Bitcoin and Ethereum are platforms that make scalability an advantage using PoW. However, if we look at the Hyperledger fabric, it considers people joining the network as trustworthy because it is a permissioned network. It also uses pBFT to improve performance (Sajana et al., 2018). A detailed comparison of blockchain platforms is given in table 3.3.

Table 3.3 The comparison of Bitcoin, Ethereum, and Hyperledger Fabric

	Bitcoin	**Ethereum**	**Hyperledger Fabric**
Permission Restrictions	Permissionless	Permissionless	Permissioned
Accessibility	Public	Public/Private	Private
Consensus	PoW	PoW/PoS	Pluggable
Node Scalability	High	High	Low
Performance Scalability	Low	Low	High
Native Cryptocurrency	Bitcoin	Ether	-
Smart Contracts	-	Can be programmed in Solidity	Can be programmed in Golang, Nodejs, Java

CHAPTER 4
SYSTEM

4.1 Scenario

A scenario was created on product shipment. In this scenario, there is a firm accessing the blockchain network. A web API that will interact with the blockchain network has been prepared for the users of the companies using the system. In addition, an interface has been designed to use this web API. According to the scenario, the user logging into the system on behalf of the company can create a new product shipment and record the transactions made during the product shipment. Each shipment corresponds to a block in the blockchain. The properties of the shipment are given in table 5.1.

Table 5.1 Object design of shipment

Property	**Description**
Id	Indicates unique identifier of shipment
Product Type	Indicates the type of product to be shipped
Unit Count	Indicates unit count of product
Grower	Indicates grower of shipment
Shipper	Indicates shipper of shipment
Importer	Indicates importer of shipment
Price	Indicates price of shipment
Status	Indicates status of shipment
Date Created	Indicates creation time of shipment
Transactions	Indicates all transactions about shipment

Every transaction made for the block is stored in the block. In total, 3 different transaction types have been determined. These are created, temperature reading, and arrived. Arrived is final status of shipment.

In the scenario, we aimed to track all operations from the beginning to the end of a product shipment through the blockchain.

4.2 System Architecture

We used Hyperledger Fabric Nodejs SDK to realize this scenario. The application we have developed consists of 3 layers. These are the blockchain network, client application, and user interface. Network layer represents the blockchain. In this layer, there are network elements, smart contract, and client SDK that we will use to access the network. In the application layer, there is a web API that accesses the blockchain and user interface that uses this API. Used technologies for implementing system, is showed in table 5.2.

Table 5.2 Used technologies for each layer

Layer	Used Technologies
Blockchain Network	Fabric Network, Chaincode & Smart Contract, CouchDB, Docker, Docker-Compose, NodeJS
Client Application: Web API	NodeJS, ExpressJS, MongoDB
User Interface: Web UI	React, HTML5, CSS3, JavaScript

We determined in channel configuration that the organization definition and the role of the organization. We created 1 organization for the test application. We created a channel and added other nodes to this channel. One of the nodes is an endorser peer that includes Ledger and smart contract. Runs the smart contract and confirms transactions. But it does not update the ledger. Anchor peer is required for larger networks. Anchor peer, if there is more than one peer of the same organization, they oversee publishing the updates on the network to other peers. Since there is only one peer in our scenario, there is no need for anchor task. Orderer is responsible for the consistency and updating of Ledger. The certification authority creates the necessary certificates for the organization's nodes, administrators, definitions, and applications. The client application interacts with the blockchain and can send new transactions to the network or query the ledger. Whole system architecture is shown in figure 5.1.

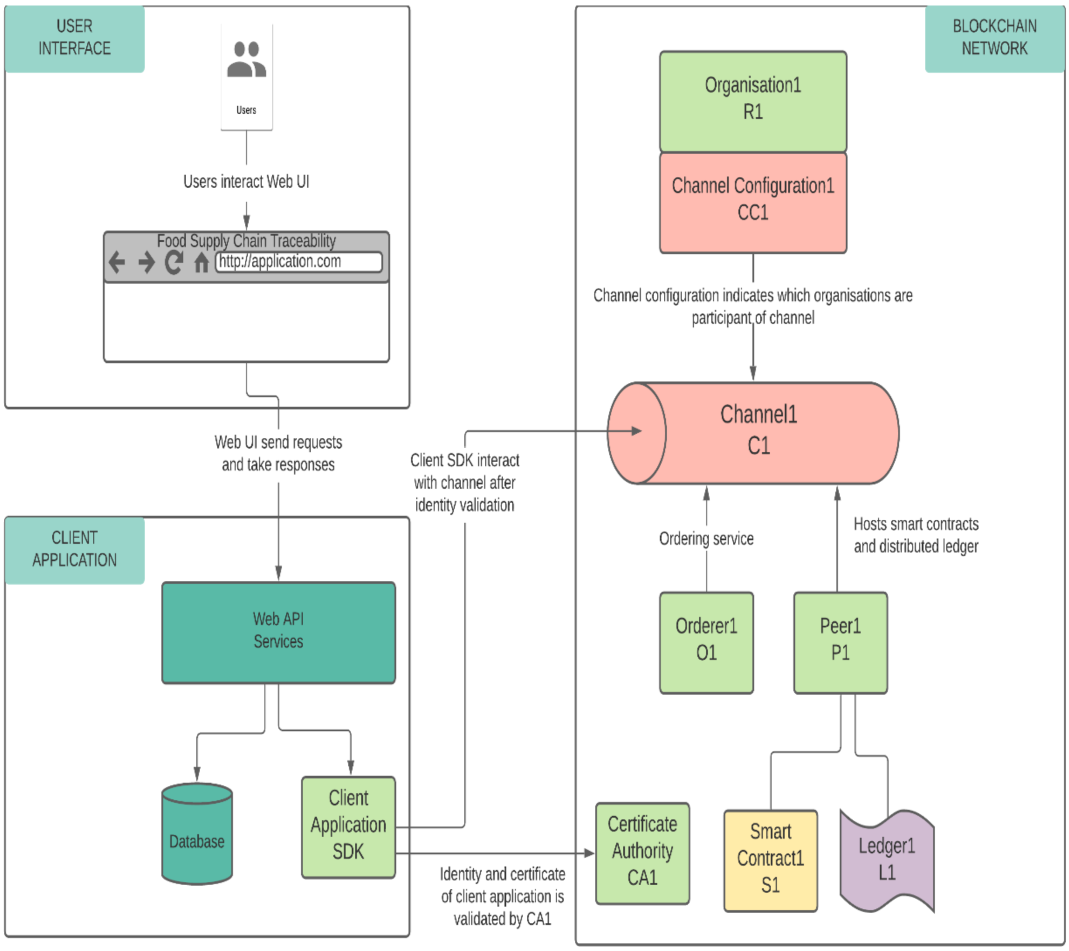

Figure 5.1 System architecture

4.2.1 Blockchain Network

It provides the distributed ledger to applications that interact with the blockchain network. In addition, smart contracts determine the rules with which transactions will be carried out on the network. Smart contracts are deployed to each peer node after the network is created. In networks where there is more than one organization, the permissions to interact with the network are provided by policies. Network policies can be updated over time according to agreement changes between organizations.

Blockchain network consists of 6 main components. These are membership Service provider (MSP), Nodes, Ordering Service, Channel, Chaincode and Database. The designed blockchain network is shown in figure 5.2.

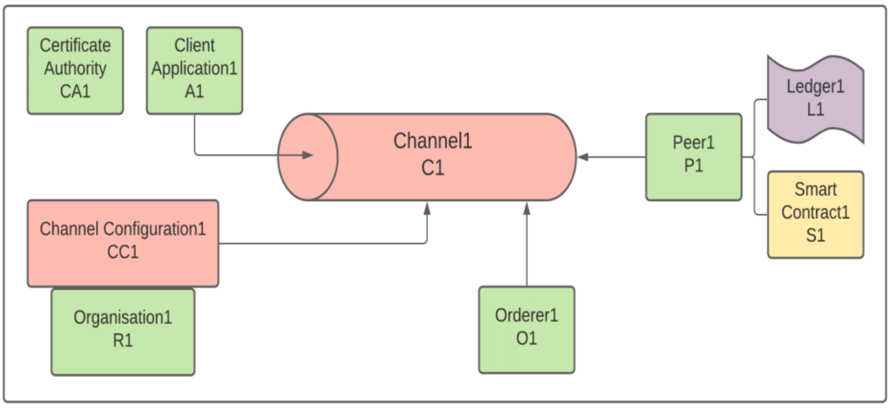

Figure 5.2 The structure of blockchain network

4.2.1.1 Membership Service Provider

It is the component that defines the permissions to access the network. Provides authentication of clients who want to access the network. It also manages client identities accessing the network. For the client to interact with the network, user certificates must also be validated after authentication. This task belongs to MSP. This authentication is provided via the Fabric-CA API with Certificate Authority. Certificate Authority has a pluggable structure. This ensures that external Certificate Authority is available in networks with multiple organizations. There are 2 different types. These are local and channel. Clients and peers in the network are determined by local. This provider defines who has admin and participant rights in the network. Channel MSP makes these definitions at the channel level.

4.2.1.2 Nodes

In the blockchain network, entities that interact with the network are called nodes. There are 3 different types of nodes. These are Client, Peer and Orderer.

4.2.1.2.1 Client. When a transaction is performed by the client in the network, it then sends a transaction call to the endorsing nodes for approval. It also broadcasts the transaction to the orderer. It has communication with both peer nodes and orderer.

4.2.1.2.2 Peer. They are the nodes that perform the transactions. They also house the copy of the ledger. The orderer forwards blocks to these nodes. In this way, peer nodes update themselves. Peer nodes can differ according to their tasks. The different types of peers and their contents are shown in table 5.3.

Table 5.3 Types of peer nodes

Layer	**Used Technologies**
Endorsing Peer	These peers approve transaction
Committing Peer	These peers commit the received block
Anchor Peer	These peers communicate across an organisation

4.2.1.2.3 Orderer. It broadcasts the transactions to all peer nodes and provides a delivery guarantee.

4.2.1.3 Ordering Service

In a blockchain network, transactions must be kept sequentially on the ledger. The order of transactions is important for the consistency of the blockchain. A newly made transaction must broadcast to all peer nodes throughout the network. This process is called ordering service. The Orderer node is responsible for this process. Hyperledger fabric is designed to support multiple ordering services. This enables different organizations to use different ordering mechanisms according to their needs. Fabric currently supports 2 different ordering mechanisms, SOLO and Kafka. The SOLO ordering mechanism is used in the developed system. It consists of only one order node. Operations can be sorted chronologically thanks to these mechanisms.

4.2.1.4 Channel

In a blockchain network, transactions are carried out through channels. A network can have multiple channels. Transactions made in the channel are visible to the participants in the channel. No one can access from outside the channel. A peer node can be connected to more than one channel.

4.2.1.5 Chaincode

Chaincode enables the identification of smart contracts. Chaincode is distributed to nodes in the network. These smart contracts determine how the interaction in the network will be. It is a set of rules. The client application can add a new transaction to the network or read the transactions in the network thanks to the smart contract. In this study, 1 smart contract was created. Smart contract consists of 5 functions. These functions, input/output parameters are given in table 5.4.

Table 5.4 Function input/output details in smart contract

Function	**Input**	**Output**
InitLedger	Context	-
AddShipment	Context, Shipment	Shipment
AddShipmentTransaction	Context, ShipmentId, Transaction	-
QueryAllShipments	Context	List of Shipments
QueryShipmentById	Context, ShipmentId	Shipment

4.2.1.5.1 InitLedger. The method creates a fixed-defined block and initializes the network ledger.

4.2.1.5.2 AddShipment. Method adds a new block to the ledger.

4.2.1.5.3 AddShipmentTransaction. The method adds a transaction to a block (shipment) in the network.

4.2.1.5.4 QueryAllShipments. Method returns all shipments.

4.2.1.5.5 QueryShipmentById. Method returns a shipment by identifier.

4.2.1.6 Database

Fabric supports two databases. These are LevelDB and CouchDB. LevelDB is a state database embedded in peers. In this database, the chain code is stored as a key/value pair. For this reason, it can only be queried with key and combined key. CouchDB stores data as JSON. Thanks to this feature, it has a wide query feature. It is also more flexible and efficient than LevelDB. CouchDB was used in this project..

4.2.2 Client Application: Web API

This layer is the Web API project that interacts with the Fabric Client Application. Web API has its own user management. It allows the use of Web API services if the user is authorized in the system. The system sends a verification email to the user when it is requested to register to the system. After person confirm requested mail, he / she can login to the system. In the future studies, admin panel can be developed for Web API and user privileges can be managed. After the user logs on the system, user can add data to the blockchain or query the data from the blockchain via Web API. Also, Web API has swagger documentation. Sample screenshots for this section are shown below. This layer was developed with NodeJS. This layer consists of a total of 6 services.

4.2.2.1 Express Service

It is a web framework used to develop web APIs. It is the service that hosts the endpoints that the user interface will interact with. Users logging into the system access the API through this service.

4.2.2.2 Mongo Service

Additional information required for the Web API is stored in MongoDB. This service enables the Web API to communicate with the database. Data writing/reading operations are provided from this service.

4.2.2.3 Authentication Service

It provides token management for users who want to access the web API. Generates tokens for logged in users. It does token validation for users who are logged in.

4.2.2.4 User Service

It is the service responsible for users' management. Adding, deleting, and updating users are provided through this service.

4.2.2.5 Mail Service

It is a service that provides mail integration with system users. In the registration process, it sends e-mail to the users for e-mail validation.

4.2.2.6 Fabric Service: Client SDK

This SDK interacts with the blockchain network. It consists of 5 layers. These are infrastructure, models, core, business, and application.

4.2.2.6.1 Infrastructure. In this layer, user credentials and connection settings to the blockchain network are kept.

4.2.2.6.2 Models. The object models which are used in blockchain are kept in this layer.

4.2.2.6.3 Core. In this layer the functions to interact with the blockchain are defined. Smart contracts are applied to these functions. If the transaction is in accordance with the smart contract, a transaction is added to the network or transactions which are in blockchain are queried.

4.2.2.6.4 Business. The business rules required in this layer are defined.

4.2.2.6.5 Application. This layer is the interface of this section. Web API accesses this section with this interface. It is the layer where business rules are applied. If request is appropriate to these business rules, this layer allow to access Core layer.

4.2.3 User Interface: Web UI

This is the client application that provides access to the Web API. With the web interfaces it provides, the user can login and register the Web API. The user can also view the data in the blockchain network from the interface. From another existing interface, the user can add data to the blockchain network.

4.2.3.1 User Login View

Users' login to the system via User Login View. Username and password are required fields. After the View receives this information from the user, it interacts with the Web API and allows the user to login. The view is given in figure 5.3.

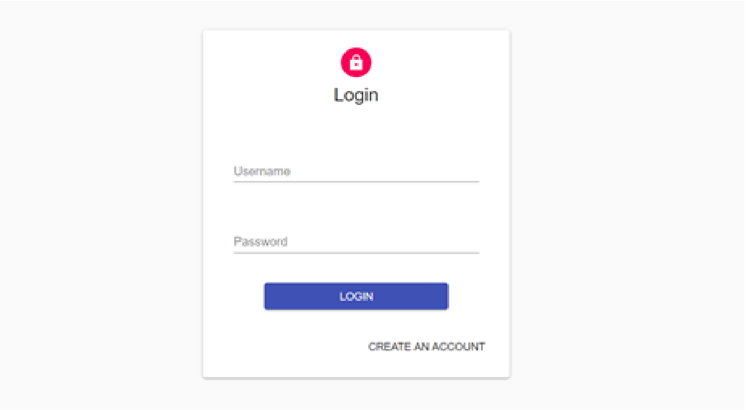

Figure 5.3 User login view

4.2.3.2 User Register View

Users register to the system via User Register View. After the necessary user information is obtained from the View, the collected information is sent to the Web API via the View. Web API registers the new user to the system after checking the information. It then sends a verify email to the user to verify the email address. Users can log in to the system after verifying their email. The view is shown in figure 5.4.

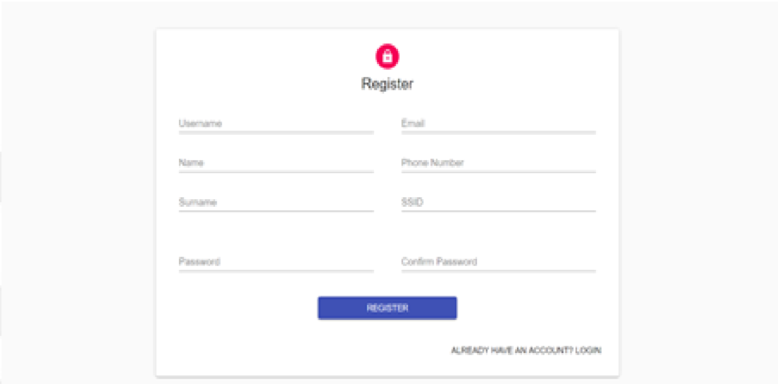

Figure 5.4 User registration view

4.2.3.3 Dashboard View

After user login, the dashboard view opens. Dashboard screen is the screen where the data in the blockchain is displayed. Dashboard view communicates with the Web API and displays all blocks in the chain along with their transaction history. Figure 5.5 indicates dashboard view.

Figure 5.5 Dashboard view

4.2.3.4 Add Shipment View

Adding a new shipment to the blockchain network is done through this view. After the information required for Shipment is received from the user, it interacts with the Web API and allows the shipment to be added to the distributed ledger. Figure 5.6 indicates add shipment view.

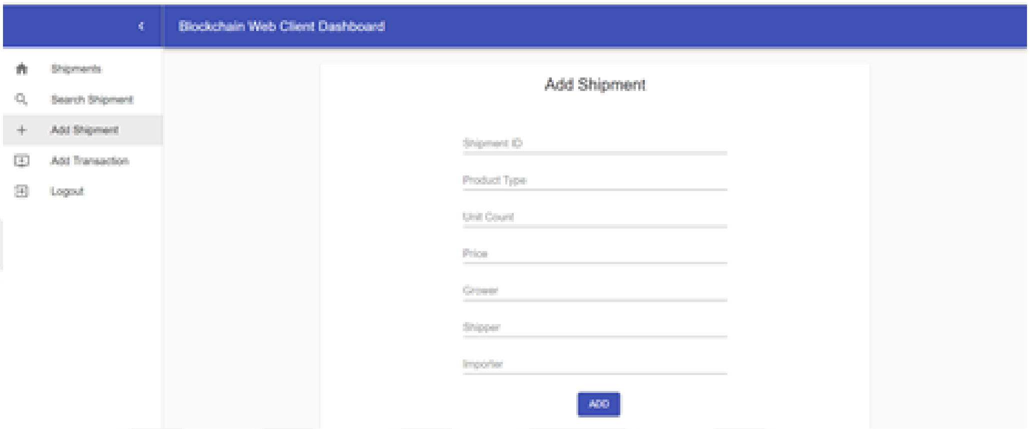

Figure 5.6 Add shipment view

4.2.3.5 Add Transaction View

It is the view that allows adding a new transaction to a post on the blockchain network. First, a specific post is searched for by the post ID. Then, the necessary transaction information is obtained from the user with the transaction add component. Then the created action is sent to the Web API with the corresponding post ID. Figure 5.7 indicates add transaction view.

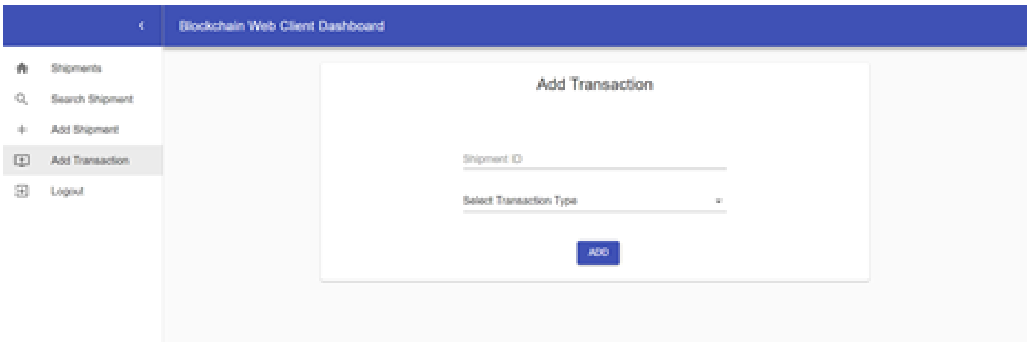

Figure 5.7 Add transaction view

4.2.3.6 Search Shipment View

It is possible to search a specific shipment in the blockchain thanks to this view. User enters shipment id as input. If shipment is found, it is displayed with shipment details and transaction history. Figure 5.8 indicates search shipment view.

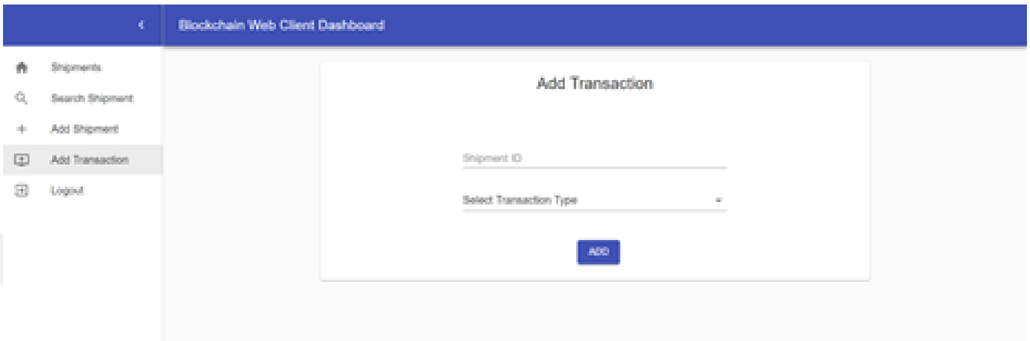

Figure 5.8 Search shipment view

CHAPTER 5
CONCLUSION AND FUTURE WORKS

5.1 Conclusion

Our nutritional needs are met through food supply chains. Many studies show that there are problems such as traceability, reliability, and transparency in food supply chains. Many solutions have been produced to overcome these problems. Most of these solutions are traditional solutions based on centralization. However, supply chains, by their nature, consist of many stakeholders. For this reason, the real solution can be reached through distributed systems.

Full traceability is difficult to achieve due to the nature of food supply chains. During the process, it is almost impossible to monitor every indicator and process with sufficient precision (Golan et al., 2004). Another issue is that supply chains consist of many stakeholders. Each stakeholder forming the chain should have the same responsibility and carry out the whole process in a technologically traceable, reliable, and transparent manner. At the same time, all stakeholders must trust each other. Cooperation between commercial partners is difficult (Barratt, 2004).

Blockchain is the most popular technology of today's distributed systems. With the discovery of Bitcoin, a lot of research has been done on blockchain which has attracted a lot of attention. Feasibility studies show that blockchain technology is an effective tool not only in financial services but also in other fields. From this perspective, blockchain is the most popular candidate for the solution of food supply chain problems. Most of the solutions produced in the studies so far are theoretical and not applied to real life.

Blockchain is still an emerging technology. Blockchain technology brings many advantages with it. Although it brings advantages, there are also disadvantages (Zheng et al., 2017). These disadvantages should not be ignored. There are some challenges to be resolved. Blockchain technology needs to be used and developed more, and the knowledge base needs to grow. However, blockchain has proven that it can solve many problems at the point it has reached today. For this reason, the type and platform of the blockchain used when producing solutions with this technology should be thoroughly investigated. The right choices should be made by analysing the requirements correctly and comparing the advantages and disadvantages.

Because of that, we investigated the blockchain types and platforms in line with the food supply chains needs in our study. We have suggested that permissioned blockchains and Hyperledger Fabric will be an effective tool for solving food supply chain problems. We created an architecture and developed an application with Fabric. Fabric provides convenience to developers with support for many popular languages. Thanks to its infrastructure and modularity, it becomes the effective tool we seek to solve food supply chain problems.

Although systems are created with blockchain, there are some difficulties in realizing it. The blockchain network is distributed and consists of many peer nodes. Therefore, the network is difficult to set up. To facilitate these processes, large companies such as IBM, AWS, Google offer BaaS (blockchain as a service) service for a certain fee. The platforms supported by each are different (Onik & Miraz, 2019). Difficulty to set up blockchain network are an obstacle for large-scale work to be done.

5.2 Future Works

The application we have developed contains a single organization. In future studies, a multi-organizational infrastructure can be provided. The reliability of the blockchain is directly proportional to the number of nodes. The higher the number of nodes, the higher the reliability. Thanks to the flexible infrastructure of Hyperledger Fabric, networks with many organizations, various channels and smart contracts can be established. The limitation of our study is that the network is installed on a machine. To overcome centralization, the system must be distributed. Fully custom and distributed network can be created with Docker-swarm or BaaS can be used.

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