Project design phase part 2

Open source framework for food tracking system

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Project Name	Food Tracking System
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Abstract

A food shortage, which has increased with the climate crisis, will be one of the biggest problems of the world, together with water scarcity, in the future and will damage the sustainability of the food supply system. With the effect of the COVID-19 pandemic, food resources are decreasing, and food prices are rising all over the world. The decrease in food sources increases the importance of food tracking even more. The exorbitant price increases after the COVID-19 pandemic are the most concrete indicators of this. Blockchain-based food tracking systems will be of critical importance because they will prevent exorbitant price increases with their contribution to food tracking processes, such as reliability and transparency

. Introduction

The awareness of protecting human health, which has increased on a global scale in recent years, has also shown itself in the food industry, and it has gained great importance that food be safe in order to lead a healthy life. Access to and the consumption of safe food is a right that every person should have. Food safety covers the whole process from the production stage of the food until it reaches the consumer [1]. More than 60% or about 1 billion tons of food is wasted within the supply chain while harvesting, processing, shipping, and storing [2]. For instance, nearly 492 million tons of perishable food were wasted in the year 2011 because of the ineffective and poor management of the food tracking systems [3].

2. Literature Summary

One of the foremost blockchain-based food tracking systems is the “Food Trust” system developed by IBM. Announced for the first time in 2017, Food Trust has provided traceability in the food supply chain to 80 different brands so far by using blockchain technology. With this traceability, the supply process from producers to consumers can be followed in detail. IBM’s open-source technology based on Hyperledger Fabric allows companies to set their own rules on the system. It is argued that the traceability offered by the Food Trust not only helps food safety but also helps producers with food freshness, sustainability, and waste.

3. Method and Applications

Hyperledger Fabric was chosen as the infrastructure on which the proposed blockchain-based system will be developed. Another tool of Hyperledger, Hyperledger Explorer, was used to provide transparent visibility of transactions in the established Hyperledger Fabric-based system. The use of these two infrastructure elements is of great importance in terms of embodying transparency and reliability features. All smart contract transactions are carried out over the Hyperledger Fabric layer. Because

blockchain transactions and processes require high performance, a need for a computer with high processing power has arisen. A device with NVIDIA GeForce RTX 3080 graphics card, Intel i7 12700KF processor, 16 GB RAM, and 1TB SSD has been determined and Ubuntu 20.04 operating system is chosen to be used.

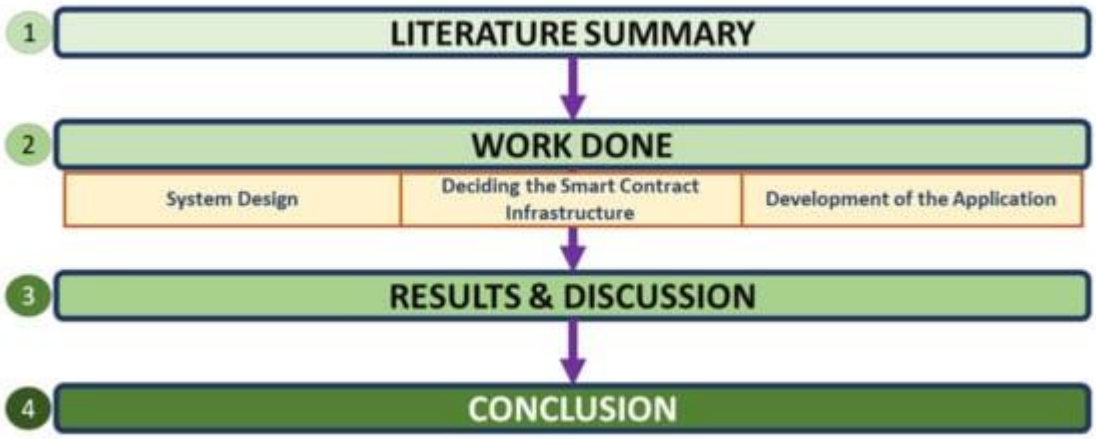

Figure 1. The methodology of the research.

There are several basic limitations to the scope of the study. First, it started by excluding foods that require certain certification for production/tracking, such as eggs and chicken. The aim is to prevent the study from becoming complicated as the identification of this type of food will require an additional layer and verification process. Secondly, it was decided that it would be appropriate to narrow the scope a little more at this stage, as there will be a wide variety of products in the concept of food tracking. For this reason, only agricultural products were included in the study, and other food types such as milk and dairy products were not included in the study. Finally, tracking of products imported from abroad was excluded from the scope, and only domestically produced foods were included.

3.1. Method

With the increasing population, food consumption is also increasing simultaneously. Accordingly, food producers or intermediaries try to reach the highest output level they can produce with their existing capacities to meet this demand and to bring the excess demand to the balance point, but the quality of these products causes various concerns in the consumer. On the other hand, the problems in the economies of the countries after COVID-19 and the decrease in the production of crops cause exorbitant price increases. At this point, the establishment of a blockchain-based food tracking system will be a solution to transparently displaying the process of food products from the soil to the end-user, both easily determining the exorbitant prices and determining the origin of the products correctly. With the system to be established, a tool that can allocate an environment of trust will be obtained. System analysis studies were carried out in line with all these needs. In the current situation, the life cycle of a product from soil to end-users has been examined. For this, various web pages were examined, face-to-face interviews were conducted with sellers and intermediaries, and how this process was carried out was investigated.

When the whole process is examined, seeds and supplement materials are purchased from suppliers, processed by the producer, and turned into products, then wholesaled in factories and delivered to retailers through the distribution chain. Finally, it is offered to the end-user, that is, the consumer. When the whole process is evaluated, it is seen that it can be constructed as a six-party system in total (Figure 2).

Figure 2. Agri-food product supply chain.

The advantages to being obtained at all stages of the system to be created and the contents of the application steps are given below:

- **Raw material purchase:** Information such as product type, amount of chemical, which is the shopping information between the supplier and the manufacturer, is recorded in the blockchain structure. QR codes can be used to automate these processes.
- **Planting the crop:** The producer records the number and type of seeds used during planting in the blockchain structure. With a smart contract to be used here, it can be checked that no more seeds are planted from the seed taken in the previous transaction.
- **Cultivation:** With the networked microcontrollers to be used here, information about the growing place of the product, how much water or sun it receives can be added to the blockchain. Again, when there is an anomaly with smart contracts, it can be recorded.
- **Harvest:** During the harvest of the planted product, adding the obtained amount to the blockchain with IoT devices can be automated and it can be determined whether the product is organic through the process from seed to harvest.
- **Delivery of the product to the fabricator:** Using GPS technology, the delivery process of the product to the fabricator can also be monitored with IoT devices.
- **Production:** The amount delivered to the manufacturer can be added to the blockchain. In this way, it is possible to monitor how much loss is incurred in the transfer phase of the goods from the manufacturer to the manufacturer.

- **Delivery of the product to the retailer:** Using GPS technology, the delivery process of the product to the retailer can also be monitored with IoT devices. The quantity and freshness of the delivered product can be recorded on the blockchain.
- **Consumption:** The consumer can view the entire life cycle of this product, all data collected, with the help of a QR code. They can also observe how the pricing is conducted in all the above transactions.

There is a need for a system flow that will achieve results with a holistic approach and meaningful activities at all these stages. For this reason, the system flow will be carried out in 12 steps, from the sowing of the seed to the consumer, taking into account these needs sequentially (Figure 3).

Figure 3. Workflow of the proposed system.

1. **Manufacturer, intermediary, and retailer parties register to the system with company details:** First of all, all of the parties that will be in the blockchain network to be established are registered and logged into the system.
2. **Control of firms is provided by governmental institutions:** It is checked whether the records of the companies registered in the system match the official sources. For example, in Turkey, this process can be carried out quickly through MERSIS (Central Registry Registration System), through web services provided by governmental institutions.

Table 1. Comparison of related works in the literature [21].

When the studies in the literature are evaluated, it is seen that food tracking systems are managed in 4 layers. These are source streaming, web server, application server, and database layers, respectively (Figure 4).

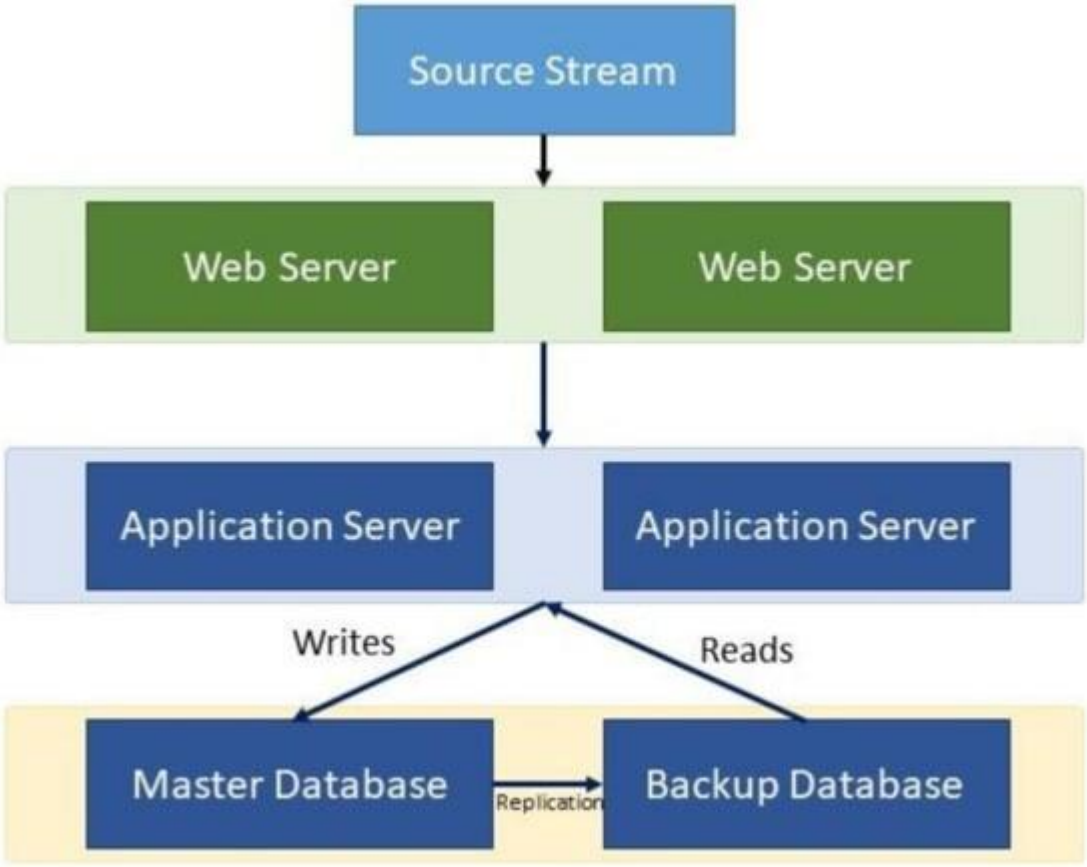

Figure 4. Conventional food tracking systems architecture.

In line with the proposed system within the scope of the study, it is recommended to add a blockchain layer in front of the existing source stream layer (**Figure 5**). With the smart contract structure, the aim is to make food tracking more transparent and safe and prevent data destruction.

In the traditional approach, the data obtained from the source are transferred directly to the application layer. At this point, if there is no additional security layer, there may be cyber-attacks in the supply chain. In addition, it is seen that the direct transfer of the obtained data to another source on a single source can only be performed in a closed way. This is an important indication that the principle of transparency does not exist in this structure. With the addition of the blockchain layer, an important line of defense has been established for the security of data. Because advanced cryptography (hash code structure) is used, the probability of successful cyber-attacks on a blockchain-based system is almost impossible. On the other hand, considering that blockchain technology allows the formation of chains by adding blocks end-to-end and the transparent monitoring of this chain, it provides an important advantage for the tracking of data. In addition, the system is not controlled by

With the proposed system, data will be obtained from the devices in the food tracking containers, and this data will be collected on the blockchain-based system. Food tracking will be carried out not only on the vehicle but at all stages of the supply chain. The distribution of the obtained data will be delivered to the end-user through the servers

After the data received from the supply chain units are passed through the blockchain layer, smart contracts are created, and all transactions are executed and tracked through smart contracts. The data obtained from the output of the process are sent to the internet layer for distribution. After that, it is propagated to the end-user to view the output of the system (**Figure 7**).

.2. Deciding the Smart Contract Infrastructure

While investing in technology, a detailed market analysis of the product to be produced with the relevant technology is of great importance in terms of obtaining successful outputs. The preparation of such reports requires significant experience, knowledge, and market monitoring. Some research companies conduct such research and present various reports, as technology companies cannot find the opportunity to make such a deep analysis in their daily routines and/or they may not have sufficient depth of knowledge. It is generally seen that large technology companies follow such external analyses while making technological investments and make investment decisions after analyzing their outputs. As one of these companies, Gartner is in the market; it is known as one of the world's leading companies in technology and market analysis. It is a prestigious company that follows emerging technologies and offers many detailed analyses. As expected, Gartner did not remain indifferent to the remarkable advantages offered by blockchain technology and researched this technology. In the report prepared as a result of the research,

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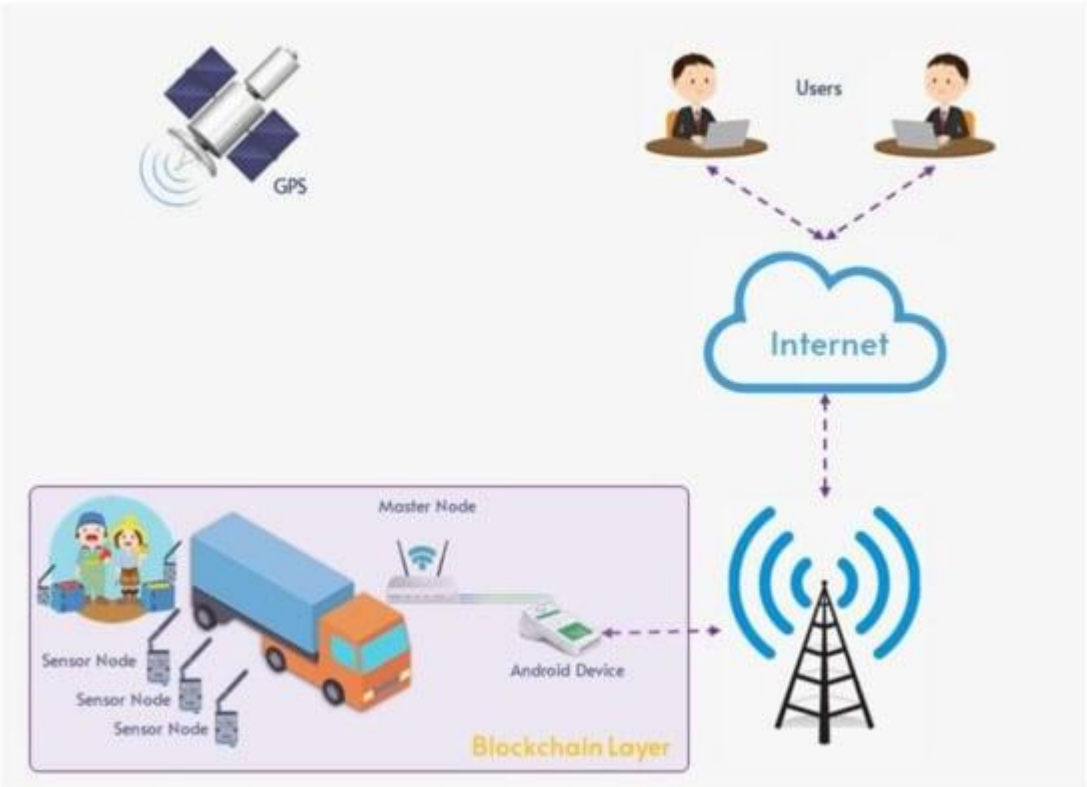

Figure 6. Proposed system components and transaction flow for real-time food supply tracking and monitoring.

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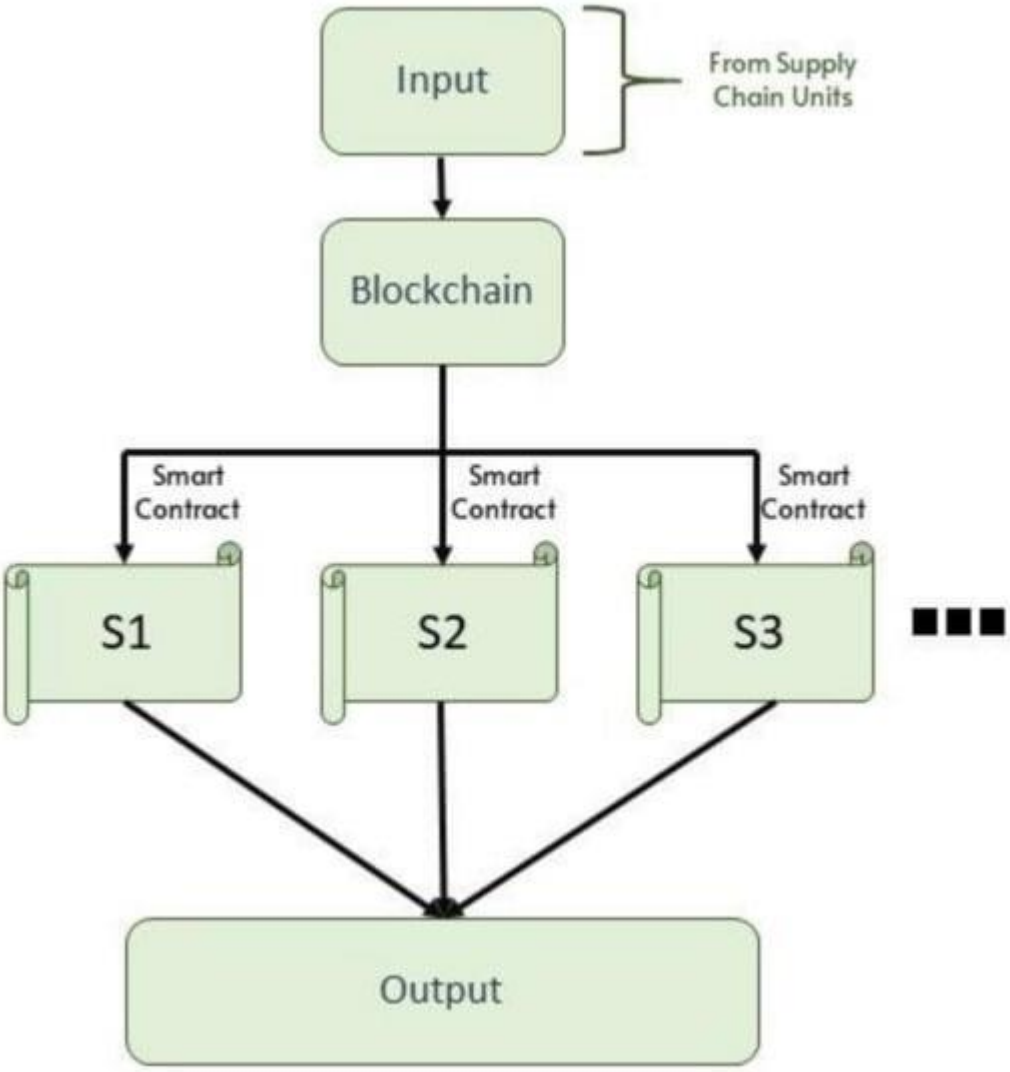

Figure 7. Proposed blockchain layer architecture.

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blockchain applications have increased, but similar results have not yet been achieved in successful private enterprise blockchain projects. When the hypecycle in which the investigations are made, according to the types of blockchain applications examined, it is seen that financial applications are in the "enlightenment trend" stage; it is seen that it will pass to the level of maturity in between 2 and 5 years. Apart from the financial applications of blockchain technology, it is widely used. Smart contract applications, on the other hand, are currently in the "trough of disillusionment" stage and will take a little longer to reach maturity; but, in between 5 and 10 years, it is seen that this field will reach the level of maturity (Figure 8) [24].

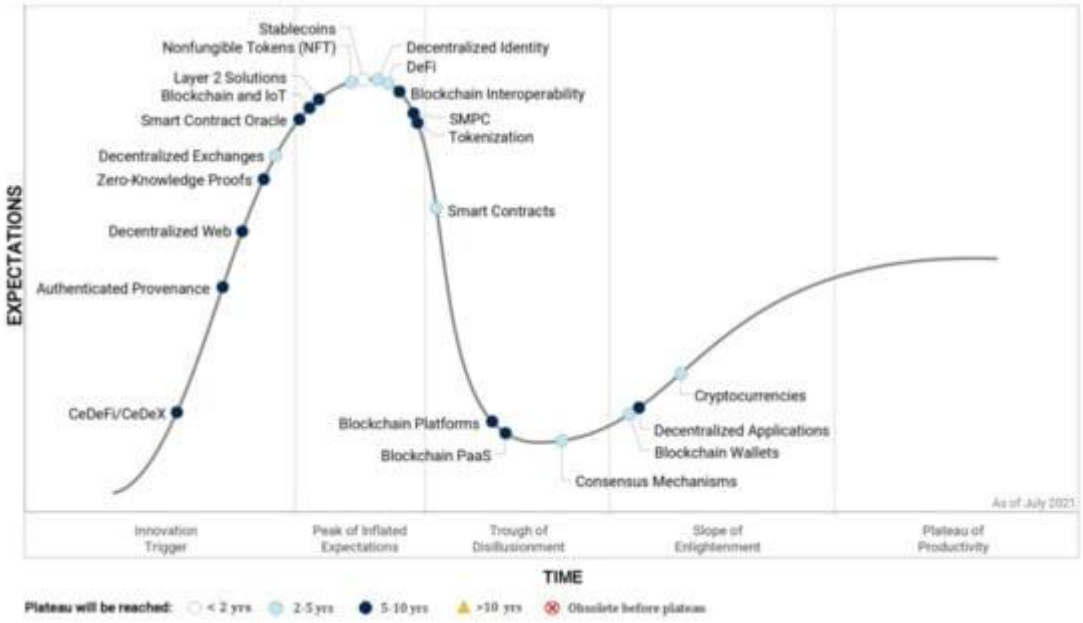

Figure 8. Gartner hypecycle for blockchain.

Although the name "trough of disillusionment" stage evokes negativity, it is a point on the way for all-new generation technologies to reach maturity. Seeing concretely that the exaggerated expectations about technology are in vain is called disappointment. After this stage, the capability of technology will begin to be considered more realistically, and the success rate of applications will increase gradually. Therefore, it looks like smart contract applications have a brilliant future ahead. A smart contract is a type of concrete computational deal between the buyer and the seller that works by writing the contract directly into the lines of code. The code and contracts here are distributed; it is located on a decentralized blockchain network. The code controls execution; transactions are traceable and irreversible.

There are many alternatives on the market that offer blockchain infrastructure. Ethereum, R3 Corda, and Hyperledger are the most prominent of them. Although all of them have pros and cons, choosing them according to the area in which they will be used is one of the factors that will increase success. An infrastructure where supply chain management can be performed will be preferred due to compatibility with the subject of the study. In addition, a permissioned network is needed where participants can be managed by a mechanism. On the other hand, performance is another important issue that needs to be addressed. The research has started to be carried out in this direction.

First of all, R3 Corda was eliminated in line with these criteria. It is an infrastructure that can be used mostly in the field of finance, whereas our application area is the field of food supply management systems. Although R3 Corda offers an advanced blockchain infrastructure for financial applications, it

has been determined that it is not suitable for this study. Smart contract infrastructures offered by Ethereum and Hyperledger companies support supply chain tracking applications.

Secondly, a flexible permissioned network to be able to identify the participants of the network is needed. While the infrastructure offered by Hyperledger fully supports this, the infrastructure offered by Ethereum partially allows this and offers a stricter infrastructure compared to Hyperledger.

The third important criterion is performance. Because performance is one of the most important elements for ensuring and disseminating the use of many applications, the proposed system should have high transaction performance to ensure this. The past studies using these two infrastructures based on performance data were analyzed. When the data provided by Hyperledger and Ethereum infrastructures such as latency, transmission/reception per second, and CPU load rates were compared, it is seen that systems developed with Hyperledger infrastructure allow processing with higher performance (Table 2) [22]. In particular, Hyperledger's Fabric solution stands out at this point.

Table 2. Ethereum and Hyperledger performance comparison values [22].

Because blockchain is a new technology, the most common problem in applications developed using this technology is the lack of resources. Because the number of applications is limited, it may take a long time to solve the problems encountered during the development phase, and some issues even seem to be deadlocked. Therefore, it is critical to overcome the problems for the selected application infrastructure preferred by technology developers. At this point, Hyperledger stands out from other blockchain infrastructure options because it is a formation that was created by the Linux open-source code community and received the support of technology giants such as IBM, Fujitsu, and Cisco.

Hyperledger Fabric is an open-source, enterprise-grade permissioned blockchain infrastructure designed for use in enterprise environments. It is the first distributed ledger platform to support smart contracts written in general-purpose programming languages, such as Java, Go, and JavaScript, rather than restricted domain-specific languages. It is specially designed to have a modular architecture. This allows Hyperledger Fabrics to be used to fit different needs. Fabric builds consensus based on the order of operations and broadcasts blocks to nodes in the network. It allows the creation of an independently configurable authentication and verification protocol per application. Hyperledger Fabric mitigates the risk of a participant deliberately introducing malicious code with a smart contract on the permissioned network. Participants get to know each other and all actions, such as presenting application actions, changing the network configuration, or deploying a smart contract are recorded in the blockchain, following a verification policy for the network and the relevant transaction type. Fabric is currently the most active Hyperledger project and offers a highly scalable system. It is also a permissioned platform and provides privacy through its channel architecture. Participants in the network must first create channels between them to perform a particular operation.

The latest version of a Hyperledger Fabric network, which was formed after all operations were completed, is given in Figure 9. First of all, an organization that will establish the N network is required. Here, the organization that established the network is R4. R4 organization starts O4 (Orderer Service) after setting NC4 (Network Config). O4 peers are responsible for installing the smart contract and ensuring consensus. R4, who has admin authority in the network, can share this authority with the R1 organization if they wish. The organizations symbolize companies or participants. If a channel is to be

created, a consortium is established to show with whom this channel will be created. With this consortium, the participants of the channel can be determined. The configuration files of the channel are located in the “Channel Config”. In addition, organizations also have an MSP (Membership Service Provider). P1, P2, and P3 are machines here. Peers carry smart contracts (S5) and blockchain (L1) inside them. Smart contracts can read and write to the “World State” of the blockchain. Moreover, each channel is connected to the Orderer Service (O4) because O4 provides the consensus mechanism that keeps all peers in sync. A1, A2, and A3 are external participants, and they do this through peers thanks to the API. For this project, the producer can be considered as the manufacturer and the intermediary. Their access to the network can be restricted within the CC regulated by the organizations. As can be seen, an organization can be a participant in more than one channel. In this case, the peer belonging to that organization can keep more than one ledger (blockchain) and smart contract (chaincode) for separate channels.

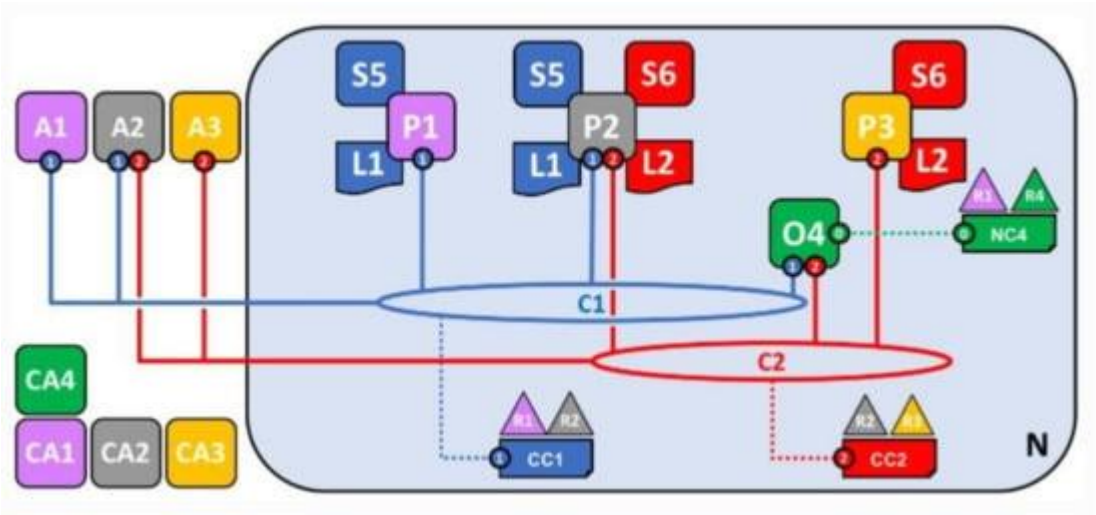

Figure 9. Hyperledger Fabric basic network architecture [25].

Therefore, with all these advantages, it was decided to use Hyperledger blockchain infrastructure within this study. There are many infrastructure products offered by Hyperledger. Fabric is the most prominent among them, so it was decided to use this to build the proposed system.

3.3. Development of the Application

After the determined system flow and infrastructure, the development phase of the system has started. The installation of the necessary environment for the Hyperledger Fabric framework has begun. During the installation, the installation documents published by Hyperledger Fabric were used. First, the “curl” tool and the “git” version control software were installed. After these installations were completed, the Go programming language tool was installed. In addition to the Go language, packages such as “Python”, “Nodejs”, “npm” were also installed. In addition, “docker” and “docker-compose”, which are the containerization technology required for Fabric to work, were also installed. Finally, Hyperledger Fabric was installed. The “/bin” folder inside the “fabric-samples” folder is set as the environment variable. The version information of the installed programs is given in Table 3.

Table 3. Package information used in the installation of the system.

After the creation of the blockchain network with Hyperledger Fabric, it became clear that there was a need for another tool to transparently display the transactions, channels, and blocks performed on the network. At this point, it was decided to use the “Explorer” tool, which is one of the tools offered by Hyperledger. Explorer can be qualified as a tool that meets all these requirements.

After the infrastructural installations of the network were completed, the stage of making the system operational with the actors determined was carried out. In the created system, the illustration in which the parties are defined is located in Figure 10.

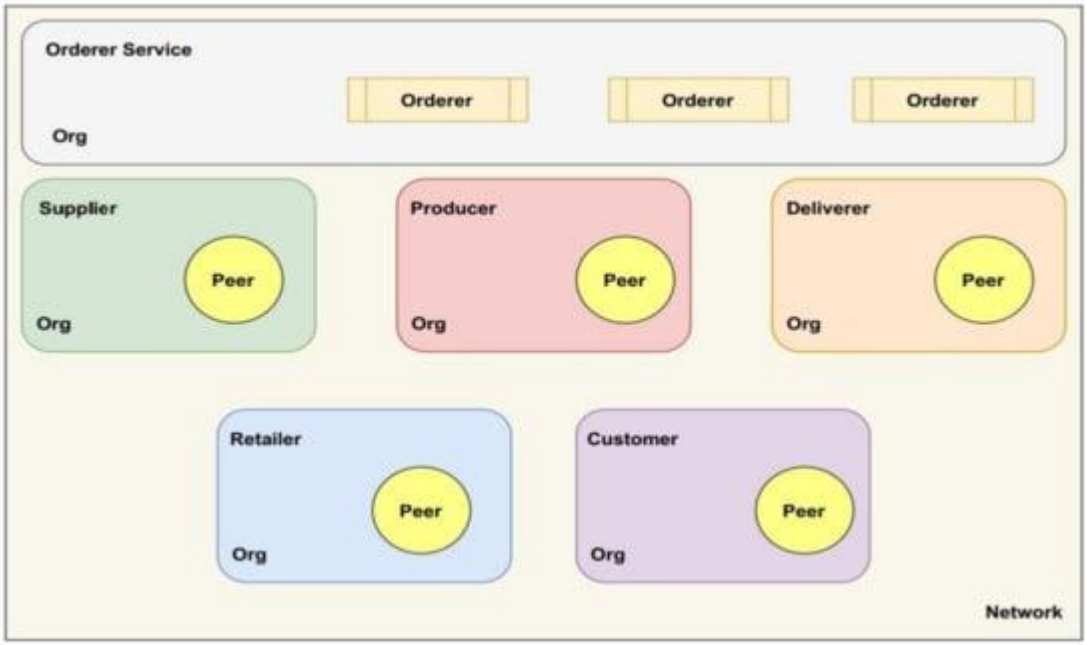

Figure 10. Parties in the developed network.

The genesis block is the most special block for all systems because it shows that the system is running and is different from other blocks. A file named “configtx.yaml” was created to create the genesis block and define channel permissions. In this created file, the permissions of the organizations, consensus algorithm, channel components, and communication ports were defined. Because this file will be used with multiple commands, a bash script file named “generate-channel-artifacts.sh” was created, which is responsible for the execution of these commands. The genesis block was created with the following code:

- configtxgen -profile AgriOrdererGenesis -outputBlock ./channel-artifacts/genesis.block channelID agriorderergenesis.
- Then, a channel configuration file named “mychannel”, including other organizations, was created and the system was started. The code is given below:
- configtxgen-profile AgriChannel-outputCreateChannelTx./channel-artifacts/channel.tx channelID mychannel.

In Hyperledger Fabric, smart contracts are called “chaincode”. In Fabric, smart contracts can be executed with Go, Java, and JavaScript. JavaScript language was chosen to implement the application. Hyperledger Fabric features the IBM Blockchain Platform interface developed by IBM for rapid prototyping of smart contracts. This interface was installed on our system as a “VS Code” plugin (Figure 11).

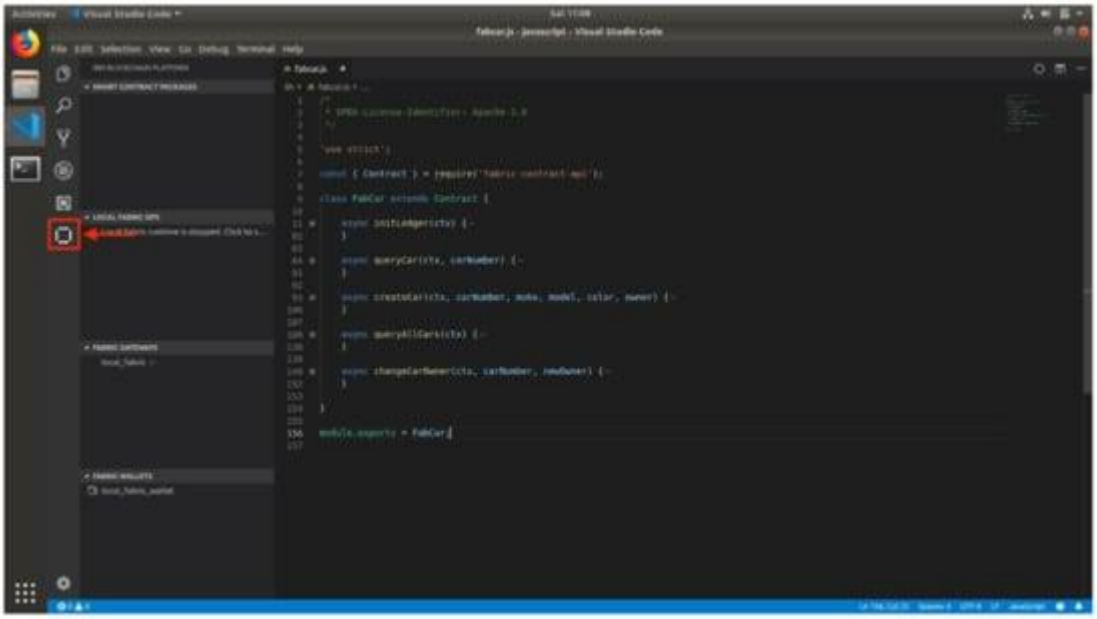

Figure 11. IBM blockchain platform “VS Code” plugin.

A smart contract structure that works in line with the system flow determined by using the VS Code interface was obtained. A sample smart contract screenshot over the developed application is seen in Figure 12.

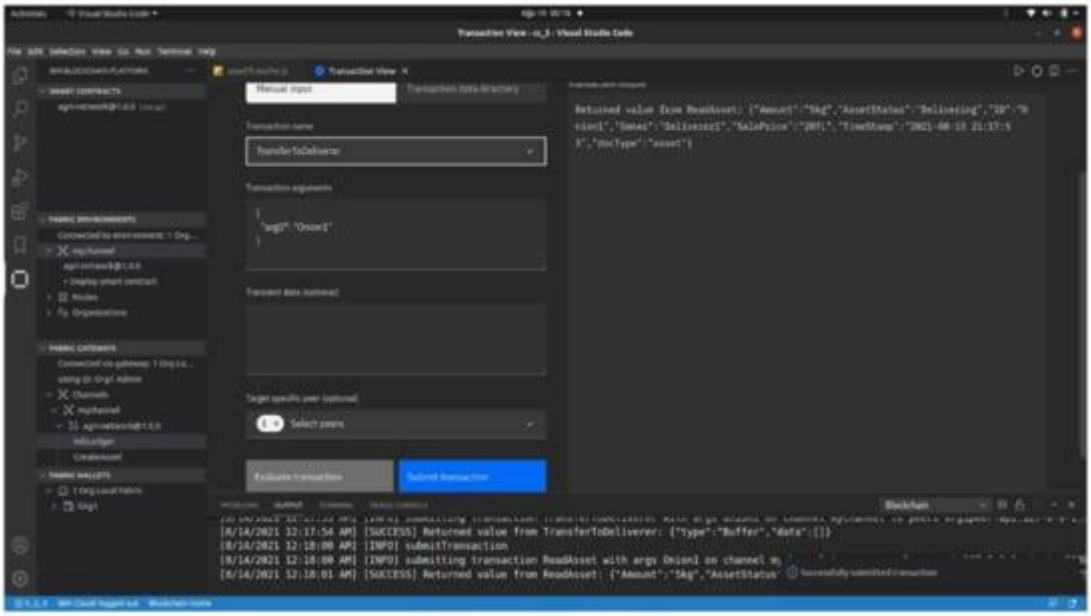

Figure 12. Food tracking system smart contract screen.

4. Results

Before using the blockchain-based food tracking system, the performance data of the system were obtained. In this way, it will be necessary to prevent problems such as scalability and to stop the work if it is foreseen that the blockchain-based system to be used will not reach the desired performance values. The performance values of Ethereum and Hyperledger Sawtooth are used to benchmark the values obtained from the proposed system. A simulation environment has been set up to collect and compare these data using Matlab. The latency (s), Net Tx (bytes), Net Rx (bytes), and CPU load (%) values

are the variables that keep the data obtained in this simulation environment. With the data obtained in this simulation environment, the aim is to reveal the difference with other platforms clearly and concretely.

Figure 14. Transaction confirmation time of blockchain-based system.

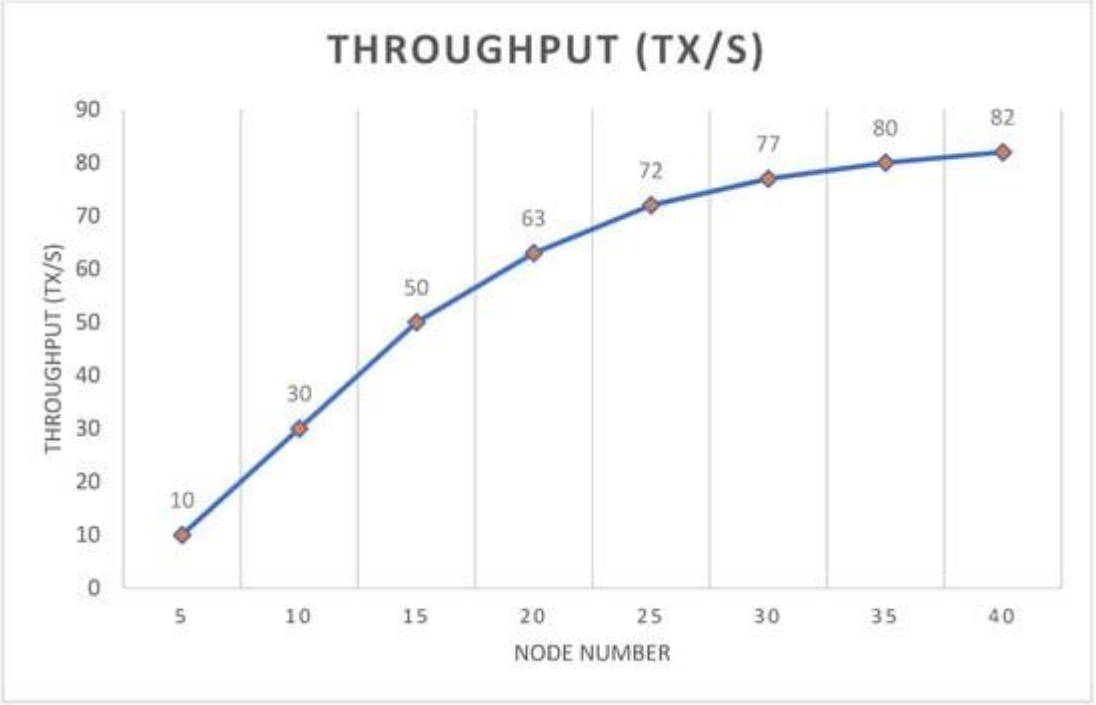

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Figure 15. Throughput value of the blockchain-based system.

After demonstrating that the performance data of the installed blockchain-based food tracking system are satisfactory and provide serious advantages, it is necessary to work on putting the system into use. The next step after the installation of the system is to put it into use, first in the pilot region and then across the country. Currently, a study on UDTS (Product Verification and Tracking System) has been carried out in Turkey and it was put into use at the end of 2018 by the Republic of Turkey Ministry of Agriculture and Forestry. Although blockchain technology is not used in this project, within the scope of

this study, the aim is to follow the food of the following products through a system, under government control:

- Supplements;
- Honey;
- Energy drinks;
- Black tea;
- Vegetable oils;
- Baby foods.

Although such a useful application was developed, it was not widely used. The main reasons for this can be listed as the lack of transparency, the need for continuous central control, and the inability to provide the right access to the end-user. Because the application we have developed is blockchain-based, we can say that basic restrictions will be eliminated with the provision of transparency and the elimination of the need for a central authority.

Because we did not have the chance to implement our application throughout the country at this stage, we took action to run the application unofficially in a pilot region and decided to implement it in a market. Therefore, we agreed to pilot the application we developed with a branch of big market chains that are open to technological innovations and have a large customer circulation in Ankara, the capital city of Turkey. With the study to be carried out in the pilot region, the aim is to evaluate the feedback that the system will receive from the users. In case the feedback is positive, the aim is to provide a basis for use throughout the country and to obtain a solid evidence base so that the performance values can be obtained from real usage data.

With the announcements in the grocery section where tomato and potato vegetables are located, we made the participants be included in the system by reading the QR code to the volunteers. Surely, we both obtained the food tracking adventures of tomatoes and potatoes on sale from the UTDS system and contacted the producers at the missing points. As a result of the studies that we carried out for 3 months (October–December 2021), we asked short survey questions of two questions each to the participants.