International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING

ISSN:2147-6799 www.ijisae.org Original Research Paper

Agri-Food Supply Chain: A Blockchain-Enabled Framework for Industry 4.0 Applications

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Submitted: 27/01/2024 **Revised**: 05/03/2024 **Accepted**: 13/03/2024

Abstract: The globalization of supply chains, rising competition, and unpredictable environmental factors accelerate business, by causing technological disruptions. Industry 4.0 technologies maximize resource use and sustainability, improving production and worker safety. Industry 4.0 has been adopted by most industries, but agriculture has received little research. Business 4.0 technology aims to improve farm resource allocation and reduce climate change disruptions. Consumers and governments seek Agri-food supply chain transparency. Instant traceability can improve food quality and autonomous decision-making in digital agri-food supply chains. Blockchain technologies are being used to provide safe traceability for agri-food chain management, product provenance, and food fraud prevention due to their trust and unchangeability. This study proposes an optimized blockchain-based smart agricultural system to address such issues. Many blockchain and smart contract-based agri-food chain management systems are product or manufacturing process-specific and hard to generalize. This research uses permissioned blockchains to determine how parameters affect performance. Our evaluation method considers the Hyperledger Fabric to create an agri-food supply chain data network and performance experiments with the Hyperledger Caliper benchmark revealed improved efficiency of the proposed agri-food supply chain system based on blockchain by comparing throughput, send rate, and latency with and without optimization.

Keywords: *Blockchain, Hyperledger Fabric, Caliper, Supply Chain,*

1. Introduction

The farming business has changed a lot over the last three industrial revolutions, from hand-harvested crops to mechanized farming and precision farming. Industrial farming makes things more productive, but it has also caused and made worse several problems. Interior and exterior environments are becoming more connected in the fourth industrial revolution[1]. With Industry 4.0, key business processes are changing quickly. Modern technologies like cloud computing, blockchain, big data & analytics, machine learning, automation & robotics, the Internet of Things (IoT), and others are transforming every industry. Digitizing supply chain management makes sense due to its complexity. Research shows that a digitally linked supply chain can cut costs by 30%, make a business faster, more flexible, more accurate, and more efficient, and cut inventory by 70% [2].

Every supply chain system must track items from origin to destination [3]. To gain end-user trust, supply chain operators must deliver accurate and efficient information. Supply chain managers must maintain process quality, integrity, and reputation. Some regulators are requiring supply chain traceability systems to be more reliable, transparent, and secure. Some governments strictly enforce these rules. Tags and bar codes are required by the Canadian government to identify item provenance [4]. The Chinese government enforces similarly. These rules increase traceability system transparency and ensure high-quality goods. Supply chain traceability systems also facilitate trade. These systems handle a lot of financial data, which makes network design more difficult. Because these networks are centralized, data could be shown in the wrong way [5]. Several network designs and distributed agreement methods have been proposed in [6] that protect the security of a blockchain while allowing for high throughput and store capacity.

Market shifts in food systems, where customers buy more sustainably produced food and encourage sustainable food production, improve food supply chain sustainability. Given the COVID-19 pandemic, consumers worldwide are rapidly shifting their buying habits toward healthy and sustainable products [7]. Because product safety is so important, agricultural and food goods need good monitoring. The government and consumers are worried about food quality, so supply chain traceability has been revived. Because it is decentralized, open, and immutable, the blockchain is essential to the growth of the supply chain. It also has smart contracts for sending company info safely. But if blockchain-based agri-food delivery networks don't work right, buyers might not trust where the food came from or

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how good it is. Bottlenecks occur because conventional centralized storage methods cannot handle the massive amount of data generated during supply chain processes. The literature suggests many decentralized file storage strategies to reduce latency, throughput, and bottlenecks. In [8], authors proposed blockchain-based soybean traceability. IPFS and permissioned blockchain smart contracts provide complete traceability in this proposed approach. IPFS is a popular distributed file-sharing network. Distributed hash tables and block exchange systems are used. A practical approach to agricultural product archival monitoring was shown in [9]. The suggested method stores transaction hashes in a separate database. IPFS data can be accessed after obtaining the transaction hash from a secondary database. An IPFS hash is retrieved from the blockchain using this transaction hash. However, a backup database failure would crash the system. A similarly auditable protocol for secure, transparent trading business transactions is proposed in [10]. Retailers, logisticians, and consumers are involved in commerce. However, the writers did not consider dealer reliability. Current trade networks have a knowledge gap between buyers and sellers. Trading firms lack trust and end users are more vulnerable to fraud due to knowledge asymmetry. Due to past research limitations [8–10], the following questions need further study:

• Is there a way to ensure the transactional hash on IPFS is always available and limit usage beyond adding storage?

• Can all network nodes share the same information while remaining trustworthy?

Can a permissioned blockchain improve the efficiency of the agri-food supply chain?

• How will a decentralised trading system conduct impartial arbitration of disputes between parties?

• How to enhance blockchain system performance?

Our study aims to complete the growing literature on blockchain-based agri-food supply chains. We are unaware of any published agri-food supply chain analysis. This study expands the blockchain-based reputation system shown in [11]. The proposed method uses hyperledger smart contracts to create a productive, safe, and reliable supply chain.

The proposed system has these main benefits: This end-to-end supply chain system includes a reputation system, traceability plan, trade and delivery methods, and an autonomous transaction system.

Authenticity, transparency, independence, accountability, and auditability are ensured. The system is scalable and auditable, making it a better alternative to current agri-food supply chains. It also has built-in security mechanisms and is resistant to common attacks. Additionally, we analyse our system's performance and discuss ways to improve it.

The rest of the paper is organized below. Section II presents system-related work, and Section III discusses the proposed system framework. Results and analysis are in IV. Section V contains the paper's conclusion, limitations, and research suggestions.

2. Literature Review

specifically allows the creation of unique business models by providing probabilities for creative activities that support entrepreneurship [16]. Smart technologies are also seen as adjuncts that can shorten the conventionalization of the food supply chain, changing the optimal distinct [17]. A major problem nowadays is controlling the effectiveness of resources in the agri-food sector on a worldwide scale. Certain problems, like those relating to energy, are universal, while others, like water shortages, differ depending on a country's economic standing [18]. Digital platforms operate as a conduit for the effects of digital changes on economic and ecological performance [19]. By promoting lean manufacturing, digital changes can decrease waste, improve logistical procedures and information, and promote flexible production while conserving resources [20]. Supply chain operations digitization may have its roots in the implementation of material requirement planning, or MRP-I and MRP-II [21], but digitization is not new since it is an essential component of modern supply chains. The food supply chain was streamlined at the downstream end thanks to ERP systems and the ongoing digital revolution in food production technology, which increased efficiency [21]. Also, the advancements in agricultural operations, such as the use of automation, robotics, and drones, have replaced the conventional modes of transportation now in use and facilitate last-mile delivery [22]. Using internet-based networks and services, the agri-food sector may increase its efficiency, intelligence, performance, and sustainability thanks to Agri-Food 4.0, a digitalization method for accelerating and supporting sustainable agriculture, land management, and competitiveness. A problem in agri-food 4.0 would be integrating population shifts, unequal resource distribution, poverty, climate change, and digital technologies. The use and management of agricultural data serve as a vital link between concerns and digital transformation capabilities [23]. Digitalization of agriculture has the potential to improve sustainability and manage territory through cost containment, real-time monitoring, and technology interventions [24]. With fully integrated digital platforms, there would be more labor- and cost-efficient supply chains with great responsiveness to market needs. [25] examined the impact of supply chain digitization, finding that enhanced capacity flexibility and demand responsiveness promoted the use of digital technology.

The agri-food industry is also adopting the practices of the Industry 4.0 concept. This is necessary because of transportation issues, drought, and a lack of knowledge about agricultural marketing and farm business planning [26]. Other contributing problems are limited access to markets, a dearth of choices for warehousing and storage, a low rate of digitization among farmers, the expensive upfront and installation costs of sophisticated equipment, and a mistaken perception of their worth. The primary obstacles affecting this business are listed by [27] as the lack of digitalization, food safety concerns, uneven and fragmented information, and environmental constraints. Three major issues plague today's agricultural food supply systems. First, the supply chain's whole cycle is lengthy because of the high number of people involved and the difficulty of communication between them. As a result of so many people being involved and the data being spread over so many different networks, individuals can't put much faith in what they're seeing. Just like the rest of our modern society, the agricultural food supply system is extremely centralized, with data that can be readily manipulated and power concentrated in a few hands. There are often lapses in human oversight [28-30], even though the central administrator is subject to examination by government agencies. Research on sophisticated traceability technology and associated systems is crucial for ensuring the quality and safety of agricultural commodities, as well as for properly monitoring product information, ensuring the safety and quality of products, and ensuring the safety of consumers.

This study examines how industry 4.0 advancements like AI, IoT, robots, blockchain, big data, RFID, etc. are converting the old supply chain into blockchain based supply chain systems.

3. Proposed Agri-Food Supply Chain Framework

The proposed methodology, which uses smart contracts to track and record agri-food supply chain transactions on the Hyperledger Fabric blockchain, is explained in this section. Our system eliminates the need for a trusted governing body by offering trustworthy and secure transactions and record-keeping for food supply chain management and safety. The proposed system is trustworthy, and secure transaction records are provided for the administration and protection of the agricultural food supply chain, eliminating the need for a single authority and allowing for decentralization.

3.1. Overview of the framework

Figure 1 shows the proposed framework with stakeholders the Agricultural Bureau, the Farmer, the Processor, the Quality Supervisor, the Distributor, the Retailer, the Consumer, and the Blockchain. The entire transparency of the agri-food supply chain system is guaranteed with the aid of hyperledger chaincode and the integration of all participants in the chain. The agricultural bureau collects data on farmers, seeds, fields, and harvests, among other metrics, and manages it centrally so that everyone can trust the numbers. Along with data about the crops' growth and environment, IPFS stores images of how the crops change over time as they are grown.

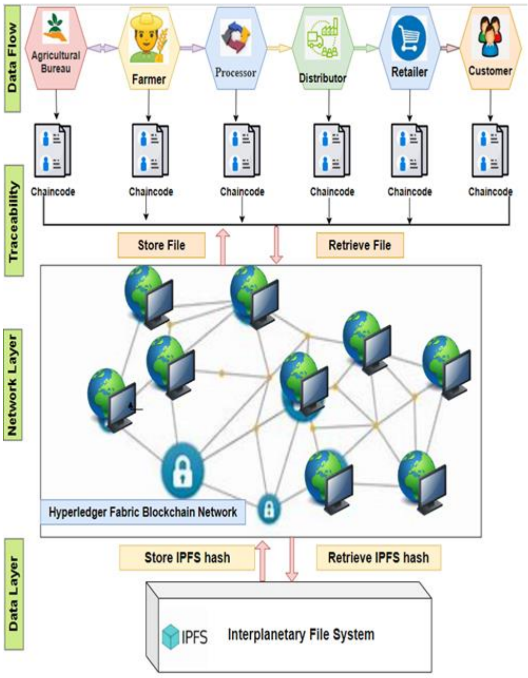

Fig 1. Agri-food supply chain framework

At a certain point in time, timestamps are full pieces of data that can be checked. They can be used to show when some of the user's info is made over the internet. The smart contract keeps track of the IPFS hash to make sure the right file is used. The farmer picks the crops when they're ready and sells them to a processor. You can be sure that farm goods are safe and of high quality with the Quality agriculture Bureau's help. Distributors buy a lot of finished agricultural items, store them, and then sell them to retailers. Retailers then sell them to consumers in smaller quantities through their stores. Data files are stored in IPFS and a hash of the file is stored in blockchain. The file is retrieved from IPFS with the help of the IPFS hash. Framework is divided into layers as shown in the framework. Data flows between various stakeholders, same data is authorized with the help of logic code written in smart contracts or (chain code). Network layers provide the backbone of the system by maintaining the ledger. Data files are stored on the IPFS network so that the network becomes scalable.

3.2. Experimental setup of the proposed system

Farm supply chains are notoriously difficult to track due to the large number of entities involved in food production. The long journey from farm to plate ends here. To ensure the legitimacy of a food traceability transaction, we collect the data, append the food's unique identification and lot number, and save the hash value. Foods warehoused together are "batch processed." The hyper ledger stores the data hash while IPFS stores the transaction data due to

IPFS's limits and blockchain data's exponential growth. To ensure that only authorized users are transacting and to secure data, a blockchain access control policy limits read and write access. Similarly, only authorized parties can execute smart contracts. The technology lets registered entities interact via smart contracts. Figure 3 shows how each component of the agricultural food supply chain is prepared, and their functions are explained below.

Agricultural Bureau: The bureau maintains a database of farmers, seeds, plots, and harvests to verify sources. IPFS stores data hash values in the ledger for integrity. IPFS keeps chain data hashes.

Farmer: The farmer plants the seeds. Farmers use sensors to track crop progress and collect data on soil, water, air, and sunshine quality, which is stored in IPFS as MPEG or picture files. Farmers must also generate IPFS data hashes for smart contracts.

Processor: Crops are harvested and sold to the processor, who turns them into the final product the customer buys and saves batch, quantity, and inspection data in IPFS. After recording the data hash on the blockchain, the package's data label is created.

Quality Supervisor: The quality supervisor oversees processing, quality supervision and inspection, and manufacturing facility and product quality inspections. Its details and hash value are stored on IPFS and the blockchain, allowing authorities to investigate and punish standardization, measurement, and quality violations, as well as counterfeiting and low-quality goods.

Distributor: The goods may go through more than one stage of distribution before they get to the store. Distributors stock and sell processed agricultural goods to retailers. IPFS stores company, product, price, and sale information, and blockchain stores the hash value to prevent tampering.

Retailer: The distributor gives the retailer bulk finished goods, which his customers buy in smaller quantities. In addition to the blockchain hash value, IPFS stores merchant information like the transaction time and date, sale amount, and more.

Customer: Consumers must buy and consume agricultural food information for traceability to work. Consumers can scan barcodes, RFID tags, or QR codes on product packaging to learn about the agricultural food supply chain.

Pictures, files, and other IPFS and blockchain data are digitally signed and given to specific users. Only the farmer who gave the MPEG files and images is responsible in this case. The blockchain smart contract could automatically punish dishonest farmers. Data-transmitting cameras are another option. These cameras would automatically upload images to a DLT. Hardware cameras for farmers to install could prevent hacking or manipulation [33]. This means anyone with blockchain access can verify the images and challenge their authenticity.

4. Implementations and Results

In this section, the performance of the proposed architectural framework is measured against industry standards and blockchain benchmarks. The results are analyzed using many different factors, such as block size, endorsement policy, and the time it takes to generate a block.

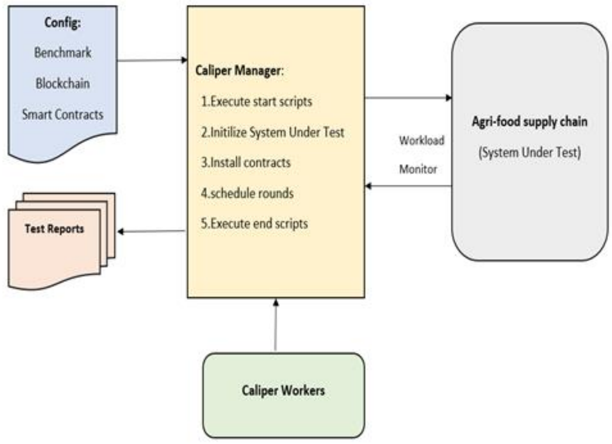

Fig 2. Performance Evaluation Framework

The performance of various instances is measured by their throughput, latency, and other attributes. Hyperledger Caliper is the benchmarking tool for evaluating blockchain applications on a network. Calipers are used to measure the framework's performance in this section (Figure 2). The Agri-food supply chain will be tested using a Performance Evaluation Framework that has a caliper manager and workers who will do work that is similar to what they would do in real-world workloads. Following the steps in a framework leads to the creation of a test report. To check how well the framework works, various factors like latency, speed, CPU usage, incoming and outgoing traffic, memory use, disc read/write, network I/O, and more are tracked. Because of the review, the block size, TPS, support method, channel, resource use, and record database setup are all changed.

4.1. Performance Effects of Hyperledger Fabric Block Parameters

On a blockchain, a block consists of several transactions each block contains information specific to that block, the block before it, and the individual transactions inside that block. For the endorsement policy, it is crucial to get the endorsements from different nodes and it is an important factor that affects blockchain performance. In this proposed blockchain application, the data related to agri-food and intercommunication on the condition of the roads is also recorded as a transaction on the block. We looked at Hyper ledger Fabric's performance to identify its weak points and provide insight for enhancing our suggested solution. The effects of various factors on the transactional performance of the agri-food supply chain are investigated and analyzed with the goal of optimizing that performance.

1. Block Size Effect: There might be several situations in the blockchain-based agri-food example, such as the transfer of data between suppliers, verifying a farmer node, etc., that could count as a block transaction in the blockchain. All of these transactions need to be validated before they can be included in a block. The client solicits endorsements from many peers before submitting the transaction proposal. The system's endorsement policy, which establishes the minimal number of peers that must support a transaction proposal, was previously determined while the system was being built. Once the minimum number of peers has confirmed the transaction, it is considered legitimate. The transactions are gathered with the certificates, public keys, and signatures of all involved endorsing peers. The pace at which transactions are processed is crucial in agri-food supply chain systems, making configuration of the block size parameter essential. The batch size, which has three parameters adjusted with the demands of the application in mind, Maximum message count, absolute maximum bytes, and recommended maximum bytes is used to change the amount of transactions in Hyperledger to fix this problem. Use the phrase max message count to denote the maximum allowed number of transactions in a block. The value of absolute max bytes represents the largest block that may be, in bytes, be. Although preferred max bytes specify the ideal block size, a block can be formed by a single transaction that is both greater than this and lower than absolute max bytes.

2. Effect of Endorsement Policy: Fabric employs endorsement rules to establish which peers must validate a submitted transaction as valid before it is recorded in the distributed ledger. In this work, we explore the implications of Fabric's endorsement policy component and model two blockchain systems to compare and contrast potential endorsement policy implementations. To achieve so, this study employs modern techniques for endorsing work.

3. Effects of Transaction Types on Block Size: Since it is unrealistic to assume that the number of input transactions in a block will always be the same, the size of individual blocks may vary. Depending on the kind of transaction, either reading or writing may be possible. The current state must be produced by read transactions. Changing the block size is a write-only operation and does not affect read transactions.

4.2. Experimental Evaluation

In this study, we benchmarked the proposed system's performance and compared it to that of Hyperledger Fabric v1.4. The Hyperledger caliper's configuration file for Hyperledger fabric v1.4 is shown in the image below. The initial phase of the analysis is to identify bottlenecks and provide opportunities for improvement. The effect of varying the rate at which the load is generated and the size of the blocks being used is also investigated. The endorsement policy's impact on the Hyperledger fabric's functionality will become clear throughout this analysis. To improve performance, The endorsement policy has to be created with fewer endorsers and sub-policies. In addition, NOutOf always outperforms And/or is less efficient.

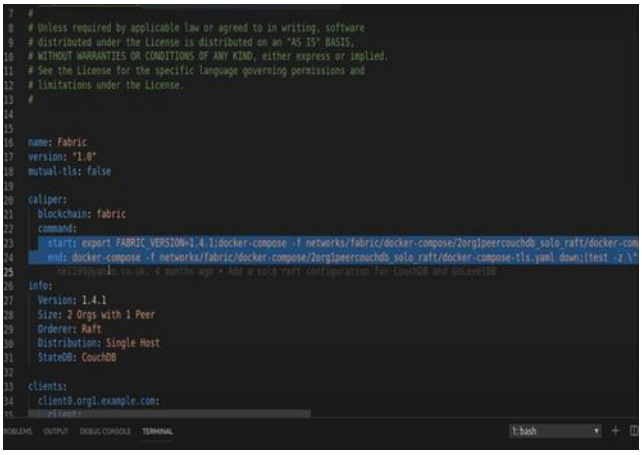

Fig 3. Caliper configuration with Hyperledger Fabric 1.4

Observation on block size configuration: When the transaction arrival rate is below the saturation threshold, it is imperative to set the block size to be smaller. It is time to increase the size of individual blocks when the rate at which new transactions are being made reaches or exceeds the saturation threshold. Existing endorsement policies: Endorsers: Or (And(A, C), And(A, B), And(D, A), And(C, B), And(D, B), And(D, C))

Moreover, it has been shown that using the cache at the right moment might enhance efficiency when the endorser's signature validation goes outside the rules. Throughput, latency, and other performance measures are all shown to be affected by changing the block size and endorsement policy.

The agri-food supply chain architecture is utilized as a system under test to evaluate the efficacy of hyperledger Fabric. Here, we use the Hyperledger Caliper Framework for Performance Monitoring. The effectiveness of the proposed architectural framework is evaluated using a variety of benchmarks and evaluation criteria. Block formation time, endorsement policy, block size, etc. will all be used to evaluate the outcomes here. Performance tests will be conducted using latency, throughput, and other factors. Hyperledger caliper, a benchmarking tool, will be used to evaluate the network performance of the developed blockchain-based applications. Fabric, Indy, composition, sawtooth, and Iroha are just a few of the hyperledger platforms it can handle. The Hyperlegder caliper is used in this article to verify and execute the framework's performance.

In this part, we use blockchain evaluation metrics to analyse the effectiveness of the current system. Success Rate (SR), Send Rate (TPS), Throughput (TPS), and Latency (S) are some of the metrics examined while using the Hyperledger benchmarking framework[35]. It is used to evaluate the effectiveness of the proposed system throughout a range of trade volumes and interest rates from 100 to 2500 active rounds at fixed, variable, and floating intervals. Throughput is the pace at which a blockchain system may commit a certain number of valid transactions. A transaction's "Transaction Latency" is the amount of time it takes to propagate over the network and take effect.

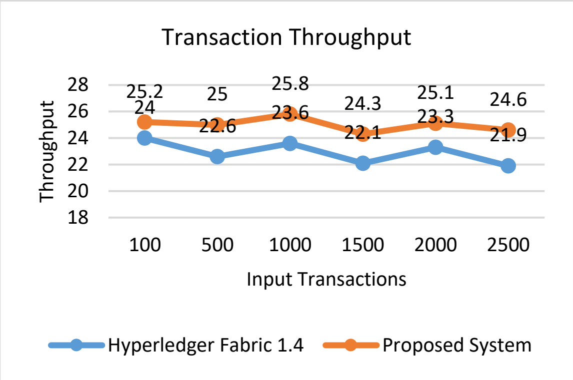

Fig 4. Comparison of Throughput of Hyperledger and proposed agri-food supply chain system

Transaction Throughput is the ratio of total committed transactions to the total time in sec-non-committed transaction. Transaction Latency is function of Confirmation Time * Network Threshold - Submit Time for transaction

Send Rate is the number of transactions successfully sent to the network for commit. It's measured in transactions per second or TPS.

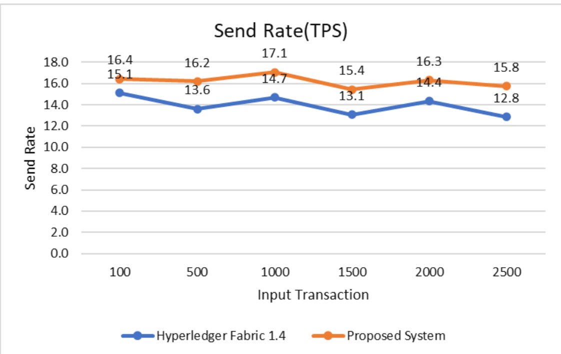

Fig 5. Comparison of Send Rate of Hyperledger and proposed agri-food supply chain system

According to the Hyperledger documentation[34], the proposed solution is compared to the performance of the Hyperledger Fabric 1.4 network.

Proposed system performance is initially analyzed with different aspects like batch size, endorsement policies, and Transaction Types. Then it is optimized by tuning these parameters. The suggested system has better throughput, send rate, and latency than Hyperledger 1.4, as shown by the numbers in Figures 4, 5, and 6.

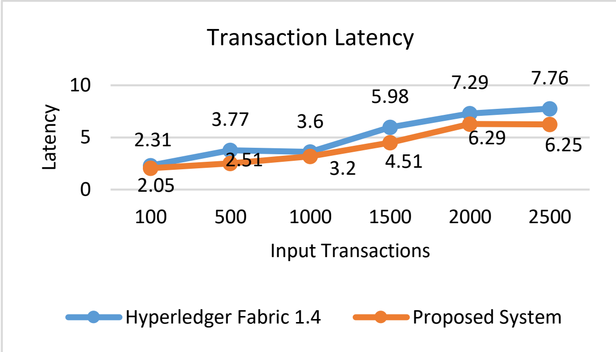

Fig 6. Comparison of latency of Hyperledger and proposed agri-food supply chain system

5. Conclusion

Industry 4.0 technology can help solve problems in the agri-food supply chain, which is good for agriculture. As a result, this study goes into great detail about the Hyperledger Fabric-based agri-food supply chain system, which makes it easy to protect entities and control who can access them. By using blockchain technology, we can control the whole food supply chain and the environment where food is stored, as well as give everyone involved several financial perks. Blockchain technology gets rid of the need for a middleman, which lowers the risk of centralized information networks and enables peer-to-peer deals that are very clear, safe, and easy to access. With smart contracts and blockchain, you can make a supply chain that is more organized, safe, and easy to track. In addition, the data lets everyone involved do thorough studies and make smart decisions. Smart contracts would make it easier to report problems with the way things are usually done. This clever plan would make the agri-food supply chain much more reliable and efficient, which would improve food safety and restore faith in the agri-food business. Also, the main point of this paper is to find the best ways to make the fabric work better given its strict requirements. Setting endorsement rules, changing the block size, and making other changes at the code level can all help get the best performance. When results are compared to blockchains from hyperledger organisations, it is found that the suggested system performs about 14% better in terms of throughput, send rate and latency.

Author contributions

Dr. Rohini Patil and Kishor Sakure did the literature study, Dr. Jayesh Sarawade and Dr. Preeti Gupta analyzed the data to find the issues and challenges, Dr. Sandip Bankar , Raju Gurav, and Dr Surekha Janrao wrote the paper, and everyone agreed on the final version.

Conflicts of interest

The authors declare no conflicts of interest.

References

[1] Tripoli and J. Schmidhuber, ‘‘Emerging opportunities for the application of blockchain in the agri-food industry,’’ FAO and ICTSD, Rome, Italy, Tech. Rep. CC BY-NC-SA 3, 2018.

[2] J. F. Galvez, J. C. Mejuto, and J. Simal-Gandara, ‘‘Future challenges on the use of blockchain for food traceability analysis,’’ TrAC Trends Anal. Chem., vol. 107, pp. 222–232, Oct. 2018.

[3] M. Turri, R. J. Smith, and S. W. Kopp, ‘‘Privacy and RFID technology: A review of regulatory efforts,’’ J. Consum. Affairs, vol. 51, no. 2, pp. 329–354, Jul. 2017.

[4] Schaub, R. Bazin, O. Hasan, and L. Brunie, ‘‘A trustless privacy-preserving reputation system,’’, Proc. IFIP Int. Conf. ICT Syst. Secure. Privacy Protection. Cham, Switzerland: Springer, 2016, pp. 398–411.

[5] M. Andoni, V. Robu, D. Flynn, S. Abram, D. Geach, D. Jenkins, P. McCallum, and A. Peacock, ‘‘Blockchain technology in the energy sector: A systematic review of challenges and opportunities,’’ Renew. Sustain. Energy Rev., vol. 100, pp. 143–174, Feb. 2019.

[6] A. Reyna, C. Martín, J. Chen, E. Soler, and M. Díaz, ‘‘On blockchain and its integration with IoT. Challenges and opportunities,’’ Future Gener. Comput. Syst., vol. 88, pp. 173–190, Nov. 2018.

[7] K. Salah, N. Nizamuddin, R. Jayaraman, and M. Omar, ‘‘Blockchain-based soybean traceability in agricultural supply chain,’’ IEEE Access, vol. 7, pp. 73295–73305, 2019.

[8] J. Hao, Y. Sun, and H. Luo, ‘‘A safe and efficient storage scheme based on blockchain and IPFS for agricultural products tracking,’’ J. Comput., vol. 29, no. 6, pp. 158–167, 2018.

[9] S. Wang, X. Tang, Y. Zhang, and J. Chen, ‘‘Auditable protocols for fair payment and physical asset delivery based on smart contracts,’’, IEEE Access, vol. 7, pp. 109439–109453, 2019.

[10] A. Shahid, U. Sarfraz, M. W. Malik, M. S. Iftikhar, A. Jamal, and N. Javaid, ‘‘Blockchain-based reputation system in the agri-food supply chain,’’, Proc. 34th Int. Conf. Adv. Inf. Netw. Appl. (AINA). Caserta, Italy: Univ. Campania Luigi Vanvitelli, Apr. 2020, pp. 12–21

[11] Panetto, H., Lezoche, M., Hernandez, J., Diaz, M.D.M.E.A., Kacprzyk, J., 2020. Special issue on Agri-Food 4.0 and digitalization in agriculture supply chains-New directions, challenges, and applications, Computers in Industry, 116, 103188.

[12] Mor, R.S., Bhardwaj, A., Singh, S., 2018a. A structured-literature-review of the supply chain practices in the Dairy industry, Journal of Operations and Supply Chain Management, 11(1), 14-25

[13] Miranda, J., Ponce, P., Molina, A., Wright, P., 2019. Sensing, smart and sustainable technologies for Agri-Food 4.0, Computers in Industry, 108, 21-36.

[14] Kirova, M., Montanari, F., Ferreira, I., Pesce, M., Diogo Albuquerque, J., Montfort, C., Neirynck, R., Moroni, J., Perrin, M., Echarri, J., Arcos Pu-jades, A., Lopez Montesinos, E., Pelayo, E., Traon, D., 2019. Research for AGRI Committee - Megatrends in the agri-food sector: global overview and possible policy response from an EU perspective.

[15] Gregori, P., Holzmann, P., 2020. Digital sustainable entrepreneurship: A business model perspective on embedding digital technologies for social and environmental value creation, Journal of Cleaner Production, 272, 122817.

[16] Lioutas, E.D., Charatsari, C., 2020. Smart farming and short food supply chains: Are they compatible?, Land Use Policy, 94, 104541.

[17] Anastasiadis, F., Tsolakis, N., Srai, J.S., 2018. Digital technologies towards resource efficiency in the agri-food sector: Key challenges in developing countries, Sustainability, 10(12), 4850.

[18] Li, Y., Dai, J., Cui, L., 2020. The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model, International Journal of Production Economics, 107777.

[19] Hoellthaler, G., Meister, F., Braunreuther, S., Reinhart, G., 2020. Function framework for describing digital technologies in the context of lean production. Procedia CIRP, 88, 167-172

[20] Kittipanya-Ngam, P., Tan, K.H., 2020. A framework for food supply chain digitalization: lessons from Thailand, Production Planning & Control, 31(2-3), 158-172

[21] Gharehgozli, A., Iakovou, E., Chang, Y., Swaney, R., 2017. Trends in global E-food supply chain and implications for transport: literature review and research directions, Research in Transportation Business & Management, 25, 2-14

[22] Robinson, M., 2017. Tiny self-driving robots have started delivering food on-demand in Silicon Valley—take a look, Business Insider, Mar, 24

[23] Hernández, J.E., Kacprzyk, J., Lyons, A., Ortiz, A., Panetto, H., 2018. Review on operational research advances in agri-food supply chains and societal challenges, 29th European Conference on Operational Research, EURO'2018, Jul 2018, Valencia, Spain.

[24] Lezoche, M., Hernandez, J.E., Díaz, M.D.M.E.A., Panetto, H., Kacprzyk, J., 2020. Agri-food 4.0: a survey of the supply chains and technologies for the future agriculture, Computers in Industry, 117, 103187.

[25] Kamble, S.S., Gunasekaran, A., Gawankar, S.A., 2020. Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications, International Journal of Production Economics, 219, 179-194

[26] Ivanov, D., Dolgui, A., Sokolov, B., 2019. The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. International Journal of Production Research, 57(3), 829-846

[27] Arora, C., Kamat, A., Shanker, S., and Barve, A. (2022). “Integrating agriculture and industry 4.0 under “agri-food 4.0” to analyze suitable technologies to overcome agronomical barriers”. British Food Journal.

[28] Liu, Y., Ma, X., Shu, L., Hancke, G.P., and Abu-Mahfouz, A.M. (2021). “From Industry 4.0 to Agriculture 4.0: Current Status, Enabling Technologies, and Research Challenges”. IEEE Transactions on Industrial Informatics 17 (6): 4322-4334

[29] Bankar, S., Shah, D. (2023). Decentralized Framework to Strengthen DevOps Using Blockchain. In: Shukla, A., Murthy, B.K., Hasteer, N., Van Belle, JP. (eds) Computational Intelligence. Lecture Notes in Electrical Engineering, vol 968. Springer, Singapore. https://doi.org/10.1007/978-981-19-7346-8_44.

[30] C. Chen, J. Zhang, and T. Delaurentis, ‘‘Quality control in food supply chain management: An analytical model and case study of the adulterated milk incident in China,’’ Int. J. Prod. Econ., vol. 152, pp. 188–199, Jun. 2014.

[31] Y. P. Tsang, K. L. Choy, C. H. Wu, G. T. S. Ho, and H. Y. Lam, ‘‘Blockchain-driven IoT for food traceability with an integrated consensus mechanism,’’ IEEE Access, vol. 7, pp. 129000–129017, 2019

[32] More, P., Ratre, S., Ligade, S., & Bhise, R. (2022, December). Design of an Efficient Approach for Performance Enhancement of COVID-19 Detection Using Auxiliary GoogLeNet by Using Chest CT Scan Images. In 2022 IEEE Bombay Section Signature Conference (IBSSC) (pp. 1-6). IEEE.

[33] Hyperledger, “Welcome to Fabric.”(2021 September) hyperledger-fabric. readthedocs.io/en/latest/ Hyperledger, Hyperledger Caliper.