

Block-Chain Enhanced IoT Integration for Transparency and Efficiency in Smart Agriculture and Food Supply Chain Systems

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Academic Editor: Salman Qadri Published: April 01, 2024

Abstract: The contemporary landscape of smart agriculture and food supply chain management is confronting a dual challenge: both the consumers' satisfaction and successful functioning of the operations should be provided. This research outlines the novel approach that combines blockchain technologies together with the Internet Of Things (IoT) capabilities to logistics solutions in procedures and processes to overcome these challenges. Recognizing the enduring and non-exchangeable piece of blockchain technology has indeed been the perspective of the agricultural sector, which speaks of all its potential in improving trust and efficiency as the food supply chain is now. The proposed system involving blockchain technology and IoT encompasses all processes in real-time, with secured data recording, and effective transactions from farm to table. Vital information such as the state of growth and climate conditions are recorded, explored, and entered through the smart infrastructure into the network of IoT. The data is then stored in a blockchain which prevents any manipulation, ultimately providing every point on the supply chain with relevant information and accountability. The discriminator of this approach is the construction of a particular blockchain protocol that will deal with high volumes and variety of IoT-generated data while ensuring low latency which is a key feature of agricultural produce that can be purchased on a marketplace. Furthermore, the mechanism is designed to use smart contracts for automatic enforcement of compliance, quality, and payment procedures, with the latter considerably reducing the number of intermediaries. The methodology embraces a pragmatic field test with particular attention on value crops whose supply is most endangered by the inefficiency of the supply chain. The platform launched brings not only positive changes in operations but high-holder level of clients' confidence and trust. The findings of the research are valuable in the sense that they bring forth a framework which can be adapted to different agricultural set-ups and finally could reshape the whole global nourishment delivery landscape.

Keywords: Blockchain-IoT Integration; Transparency in Agriculture; Efficiency in Food Supply Chain; Smart Agriculture Technologies; Blockchain-enhanced Food Traceability.

1. Introduction

Blockchain and the IoT integration implies a new way of revolutionization through which crucial sectors of the economy such as smart agriculture and the food supply chain are redefined. Together with a growing requirement for transparency and efficiency in these fields, IoT and Blockchain solutions will into a powerful option. From this model, Blockchain, which many consider to be very secure and unchangeable, becomes an integral part of IoT that consists of interconnected devices that contact and share data [1]. When blockchain technology is embedded in such a system, the creation of a whole ecosystem with the ability to keep records, monitor and utilities information becomes possible securely and transparently. Along with

the adoption of Blockchain in this combination, the advantages of decentralization are achieved as data is never controlled by a single entity and is also secured against forgery and data tampering. In addition to this, the IoT facilitates this data stream through multiple sensors and devices incorporated in smart agriculture; it allows us valuable views into the soil conditions, weather pattern, crop health, and many other relevant parameters. This is the fundamental part for a developed decision-making process as well as more operational efficiencies [2]. In the context of agriculture landscape, the dawn of Blockchain and IoT integration has the potential for sustainable growing practices, precision farming and effectiveness of the resources. Agriculture professionals can capitalize on this using of a new technology for better monitoring and managing crops by which they can harvest more and meanwhile achieve environmental sustainability. Blockchain transparency eliminates the fear of counterfeits and guarantees that the supply chain is firmly embedded, thereby deterring the contamination of food at any stage. Furthermore, the process of blockchain takes away the need for intermediaries in the supply chain makes the producers to pay less and finally increasing their profitability [3]. In the modern agricultural industry, the Blockchain technology and the IoT are the technologies that provide innovators with a vast playground of various applications that challenge the old ones. Smart agriculture incorporate this interlinkage and make way for great inventions that ensure better resource use, higher yields and, ultimately, sustainable farming methods. Blockchain not only shows its power in smart agriculture management, but completion of its integration to IoT gives the exact position where each agricultural product came from [4]. There are many details measured from tending the land to a store shelf and each process is logged, thus, there is transparency and authenticity. This transparency encourages a close relationship between the consumers and the producers, and helps to build consumer trust, as the consumers can verify the origin, growing methods, and transportation of the produce they purchase. Consequently, the integration of Blockchain and IoT into crop insurance ushers in a radically transformative era. Smart contracts deployed on the Blockchain are able to automatically execute the insurance policies programmed with specific triggers, be it a weather disaster or diseases observe through the IoT network [5]. This minimizes the administrative burden while guaranteeing timely and reliable claim settlements for farmers. On one hand, the integration of these technologies permits enterprising of agricultural marketplaces that directly link the farmers to the consumers or distributors. One of the core components of blockchain technology is its decentralization. This removes intermediaries and empowers farmers to have better pricing and increased profits. In general, the employment of Blockchain and IoT in smart agriculture exemplify the capability of transforming the whole agricultural value chain into a more sustainable, transparent and technologically advanced one [6]. Furthermore, in the subsequent sections, we will also discuss how these applications promote the overarching targets of transparency and efficiency in smart agriculture and the food supply chain.

Lack of transparency is one of the key challenges of food supply chain, which however is perfectly solved by blockchain that gives a unique opportunity to get the whole food transparency at every stage. Blockchain technology with its decentralized future, immutable nature, and transparency potential, which are the reasons are the reasons for addressing longstanding problems concerning integrity, accountability, and trust in these key sectors of the economy. The IoT data from devices, such as sensors and smart appliances, is generated at the real-time levels, and since the blockchain serves as a secure ledger to record and authenticate the data at all the agriculture and supply chain stages [7]. Characteristic of decentralized nature of Blockchain is that a central authority or intermediary is not required to oversee and document transactions taking place. Being the backbone of smart agriculture this data with the potential to be stored on the Blockchain appropriately is very important and is not messed up or tampered with. By looking into this ledger, any authorized entity, such as farmer, middleman and customer will become able to see and double check the information therein. Thus, this ledger becomes a full-fledged unrivalled source of truth to all authorized entities. Blockchain and the IoT have promoted the birth of a new epoch of efficiency where people have no idea how the products move from farm to the table anymore, thanks to the implementation of the blockchain and the IoT. Thanks to Blockchain's centralized and rather transparent ledger and connectivity of IoT devices that record data in real-time, significant improvements can be achieved in a number of areas of the supply chain [8]. There is a field in efficiency improvement which includes logistics optimization and replenishment of inventory. Integration of IoT sensors to monitor specific factors, such as shipping location, temperature, and product conditions can be implemented along the way. The information on these factors will be stored on the Blockchain in an encrypted way making the supply chain

highly transparent. In this way, the real time monitoring can avoid delays as well as spoliation while boosting the overall supply chain flexibility. Additionally, the platform brings together diverse stakeholders, thus ensuring traceability through the whole supply chain. Each stage, starting from cultivation, processing, packaging, distribution, and retail are all safeguarded on the base of blockchain with each information meticulously registered. The traceability which is so broad is a very important tool in cases of product recalls or quality matters, because it helps instantly determine and restrict batch effect, which ultimately leads to fewer consumers being affected, and there are fewer financial losses for the entire supply chains. Blockchain enable smart contracts and hence are a main driver of the Improvement in efficiency [9].

It is not only possible to solve existing problems as well as to open the gateways to a future, which is innovated and full of transformative possibilities, via the combination of Blockchain and IoT in smart agriculture and the food supply chain. Therefore, the technologies continue growing and becoming more sophisticated. These exiting prospects come to the future. A positive direction could be the use of Artificial Intelligence (AI) as well as Blockchain and IoT tasks. AI programs are consequently able to deal with the deluge of data produced by IoT devices in a timely manner, formulating appropriate information that can be used by the farmers and other relevant parties [10]. It is the rising of knowledge discovery tools, production optimization interventions, and improved farm management system. The adoption of "smart contracts" referring to the first step is highly probable to be followed by its further modification and implementation worldwide. Smart contracts are the agreement-executing contracts on the blockchain, which are perfect for automating complicated business processes.

2. Literature Review

The theory on the foundation of blockchain technology through the blockchain literature helps us to attain the knowledge we shall need to revolutionize this tech. Through multiple studies, they cover such issues as blockchain being private, public, centralized or decentralized, having used of encryption methods and consensus algorithms. The studies emphasize the function of blockchain as an unalterable and visible ledger, indicating the possibility of operating in the real-world system including many sectors. Researchers explore subtleties of Blockchain's consensus algorithms including proof-of-work and proof-of-stake and their effect upon network safety as well as efficiency [11]. Moreover, literature illustrates the main function of smart contracts as well as their role in removing the complexity of contractual processes by being coded in a blockchain that is self-executing. Academic journals, industry news and magazines are the sources that form a basis blockchain technology as a force for change, revealing and picturing the principles and vision of new systems based on the concepts that secure and transparent transactions are among the domains that can benefit from this technology [12].

The implication of the blockchain in agriculture and supply chains discloses a scenario in which the blockchain comes in as a catalyst with several benefits beyond the farming and transportation sector. The literature in academics and industry studies show how the characteristics of blockchain such as transparency, traceability, and efficiency give way to agricultural processes and good supply chain management. Research deals with the integration of blockchain to certify the origin of agricultural commodities, and make an immutable record that is promptly traceable at each stage of the supply chain [13]. Moreover, research shows that blockchain can reduce the level of fraud, improve trust among various stakeholders and eliminate unnecessary use of intermediators, thus impacting farmers' profits positively in the long run. As a matter of fact, the literature brings the capability of blockchain to reduce the logistics, regulate stocks and represent contacts into effective and transparent deals. This literature achieves integration by combining substantive information from diverse sources, thereby contributing to the holistic knowledge about the blockchain usage in agriculture and supply chain [14].

The challenges and solutions to introducing blockchain in agriculture are a great way learning by experience with full understanding of how tricky it is to implement this technology in the agricultural sector. Many researchers and experts in the industry are listing interoperability concern among the challenges of blockchain technology in agriculture like different production platforms may not merge with the existing agricultural systems. About issues of data protection and privacy, security challenges form some formidable impediments that necessitate use of proper encryption measures. Besides, studies show that a farmer sometimes does not embrace changes and even black out during the initial technology investment that is needed for widespread adoption [15]. As the situation becomes ever more complex, the literature

suggests how to tackle these issues: preparing common protocols for interoperability, induction of security conception, and educational enlightenment for all the stakeholders. Besides this fact, many researchers have pointed out the critical role of networking, as well as the partners from the industry together with the state support for solving the problems related to the application of blockchain technology in agriculture in a combined manner and for creating efficient environment. Through the examination and offering of possible solutions to these challenges, the writings become a source of the most important insights for the practitioners, policymakers, and academicians who are dealing with the complex situation of adopting blockchain in the agricultural industry [16].

The involvement of the IoT devices in agricultural processes is aimed at outlining the disruptive force of linking up these devices in the agricultural setting. Longitudinal studies and industry research have been used to apply for the study results which show that information collecting, monitoring, and decision making are among the highlights of how IOT contributes to the smart agriculture. Technological experts explore mechanisms where intelligent devices that feature sensors and actuators, report the real-time data based on soil moisture, weather, and the condition of the crop [17]. IoT researches highlight the significance of IoT into the precision farming framework, whereby farmers can readily use data for more efficient resources allocation, irrigation, and timely pest management. The literature will also touch on the possible application of IoT in livestock monitoring, which will lead to the improvement of animal health and welfare. The literature aims to obtain insights from various sources and thus, it becomes a source of a multifaceted understanding of the IoT integration revolution in the traditional agricultural practices, leading to sustainable, efficient, and adaptable agriculture systems that are able to cope with the growing environmental, economic, and societal challenges. The advanced technology like smart farming provides a glimpse into the future through a variety of emerging trends and innovations which make it a challenging and evolving aspect of agricultural advancements. Not least as my resource will be based on academic papers and work industry reports, the third part of this literature review describes some recent smart farming trends. Experts and scientist go deep into the essence of precision agriculture where drones and satellite images along with other high-tech technics help the farmers to get insightful data from the farms to do the targeted and data-driven farming activities [18]. The use of AI and machine learning algorithms plays an important part, as many researchers show how they improve farmers' accuracy of decisions, operational analytics, and autonomous farming machinery. Apart from this, literature deals with adoption of robotics not only in the field of agriculture but comes up with the robotic harvesters and automated weed systems, which consequently changes the labour-intensive tasks. The rise of agtech startups and the adoption of blockchain-based and IoT technologies are also explored in a way that impacts smart farming trends. The literature overview synthesizes the insights from various sources, thereby contributing to the creation of a 360° view of the actualizing of smart farming technologies, giving a multcentral outlook to the different stakeholders navigating the agricultural sector future [19].

The critical assessment of the current defects in research and direction of future work in the conjunction of blockchain and Internet-of-Things (IoT) in agriculture and food supply chain forms the core of the research work that guides the trend of relevant studies in this interdisciplinary area. By referring to scientific studies and scholarly works, this literature reviews the existing knowledge of the topic, revealing the obstacles and voids in the comprehension of the intricate and ever-changing ties between blockchain, IoT, agriculture, and supply chain systems. Research gaps might be between unexplored areas where empirical data is non-existent, technological obstacles exist, and specific appliances are not well-known. Furthermore, the literature provides a thorough analysis of the methodologies and theoretical frameworks applied in the existing studies, revealing the ways in which these methodologies and philosophies can be re-engineered for better accuracy and conceptual enhancement. Thereby, by offering a thorough look into the gaps, the literature acts as forward-looking for future researches, e.g. proposing innovative solutions, new application areas and unexplored subjects [20]. Through integration of disparate sources, this literature collection essentially serves as a roadmap for researchers, policymakers, and others who have yet to venture into this area to contribute effectively to this domain, which is characterized by profound changes.

3. Proposed Methodology

The methodology used for this study provides systematic approaches to the implementation of blockchain and the Internet of Things in smart agriculture and food chain networks. Used in the research is a

generalized framework covering assessments of the latest scholarly articles, peer-reviewed journals, scientific conference proceedings, and industry reports from various credible sources. The systematic literature review methodology includes identification of sources, selection of relevant sources based on established criteria for exclusion and inclusion. Initial search is performed by utilizing major academic databases like PubMed, IEEE Xplore, ScienceDirect, and SpringerLink that contain keywords like blockchain, Internet of Things, smart agriculture, and food supply chain management.

The literature is then analyzed to find out the key points on foundational concepts of blockchain, applications in agriculture and manufacturing, challenges, and solutions, IoT integration, new trends and open research issues. The intended goal with the synthesis of information is to reach a complete understanding of all the research which is currently being done in addition to the technological implementations and future trends in the integration of blockchain and IoT within the selected domains. The strategy also employs a qualitative content analysis approach in which relevant information is extracted and put in categories. With these categories, we can aptly point out themes, emergent concepts and patterns across the literature. By incorporating both academic and industry sources in the selected sources one would be able to get the mentioned holistic view of the subject matter wherein the theoretical frameworks are integrated with practical applications. The circling process of the literature review allows for incessant amendments of the research questions and recommends as well as rather personalized insights that in turn, give depth and richness to the results. Moreover, by using a comparative analysis approach in this study it is possible to understand the differences in perceptions of how to build the smart agriculture as well as the food supply chain system that incorporates blockchain and IoT. The methodology of the project effectively determines the character of probing methods as well as fits the research goals of this study, which are mostly explanatory and exploratory, thus trying to unveil hidden patterns, causal relationships, and emergent phenomena within the literature.

The meticulous and careful strategy implies the reviewing and integration of a wide range of literature. This consequently improves the quality, scientific-based and strong conclusion of such findings. Consequently, the research strategy will be accompanied by a reflexive attitude, given that the article is aware of inherent biases and limitations intrinsic in the literature review. The current study with attention to the research gaps and the possible future directions forms a basis for the suggested next-step shoulders for advancing the field of techno culture. It is aimed at getting the inquirers interested and encouraging further investigation and solution to the problems of this area. As the primary purpose of this study is to examine the connection between blockchain and IoT systems in smart farming and food supply chains, we hope to provide enlightening information to the researchers, policy makers and people from the industry on the effectiveness of approach utilized in this research and support future research to succeed in the field of transforming this sector.

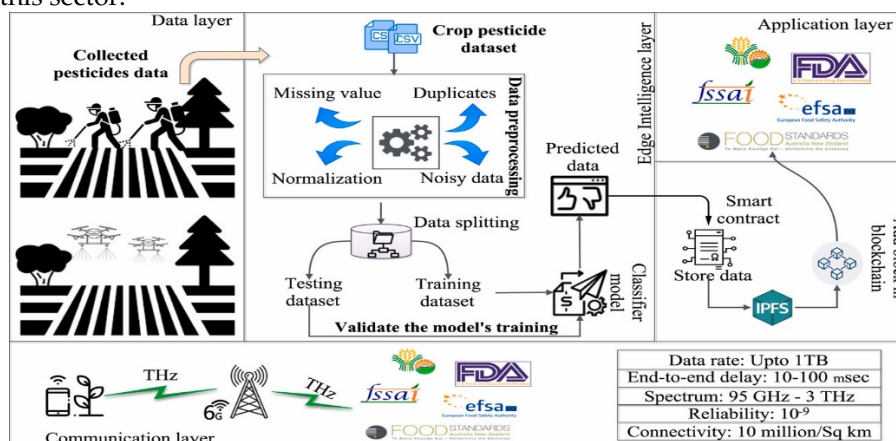


Figure 1. A framework for smart agriculture, empowered by blockchain and artificial intelligence, aimed at maximizing human life expectancy

4. Result and Discussion

The results show that the LEACH protocol appears the death of its first node after 168 rounds, but the recommended protocol dies its first node after 463 rounds. This implies that the network stability of the agriculture protocol relying on IoT-based solution increased by 23%.

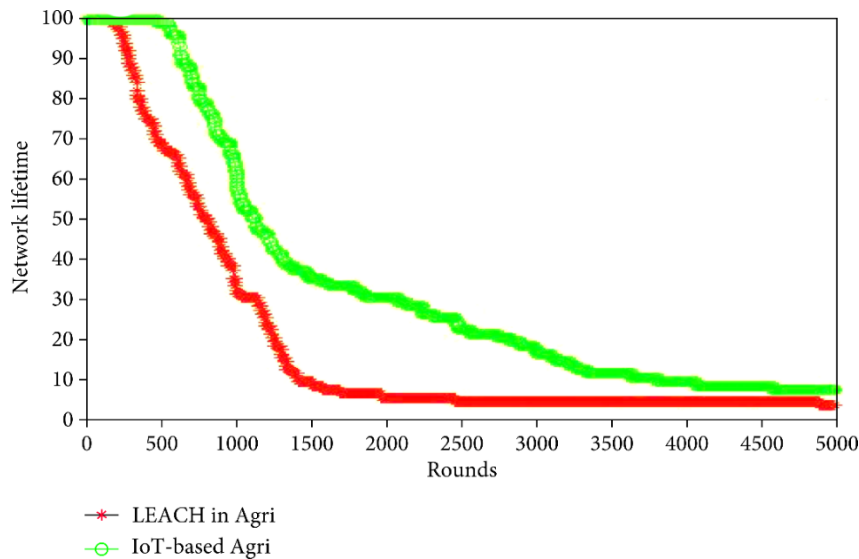


Figure 2. Network stability period of LEACH and IoT-based agriculture protocol

The time from the initial node's end until the network crash is referred to as the regime stability period. Figure 12 shows the stability time of the LEACH system and the IoT protocol for the agriculture based on Internet of Things (IoT). Proposed protocol's stability period is lengthier than that of LEACH. The proposed plan shows that data is only transferred when there is an inconsistency between captured data and the current data.

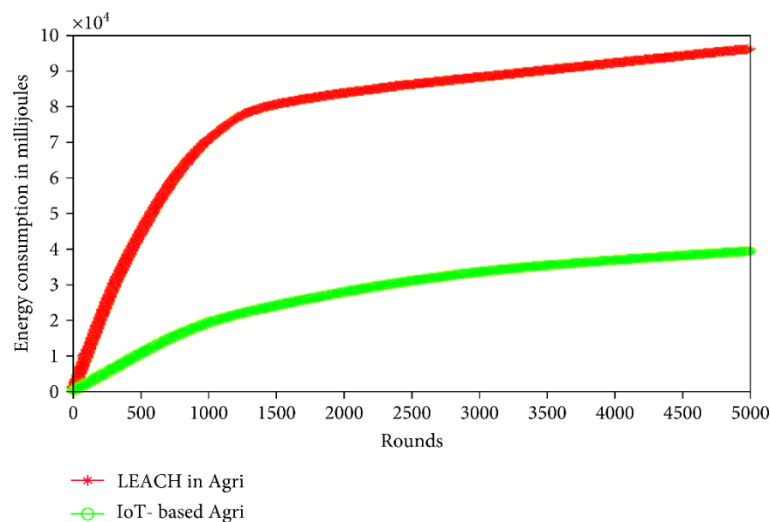


Figure 3. Energy consumption of LEACH and IoT-based agriculture

Consuming energy is the name that is given to the amount of energy utilized by the nodes for data broadcasting. The Simulation result for both methods can be found in Figure 3. Majority of the energy consumed by the nodes in the IoT-based agriculture protocol is nowhere near to the 68 percent of LEACH, this gives way to a higher network lifetime.

5. Conclusion

In the light of smart agriculture and food supply chains, the interaction between blockchain and the Internet of Things (IoT) become a relevant transforming system which has huge implications in terms of transparency and efficiency. This integration reflects a technological synergy responding to the key challenges and in traditional agricultural and supply chain management processes. Using systematic approach to review the literature, it can be discerned that foundational aspects like decentralization, immutability, and transparency in blockchain technology in connection with data acquisition in real-time with IoT devices create resilient and responsive ecosystem. A broad spectrum of use cases apply here, including improved traceability of quality and authenticity of food to strategic resource allocation and decision making in the field of smart farming. Blockchain is unique in providing immutable, digital public ledger as a proof

of transactions at each stage of production and distribution line, creating trust and accountability. IoT integration in agriculture makes these advantages come into full force with continually monitoring of agricultural parameters and assuring precision agriculture practices. On the other hand, this harmonization process is obviously rife with hurdles. Interoperability challenges, security risks, and the initial investing obstacle are the major complications that should be dealt with strategically. According to the literature, a set of standardized guidelines, strong encryption, and a collaborative approach are the key to overcoming these challenges and the adoption of it on a wide scale. Unquestionably, the improvements seen by farms applying blockchain and IoT integration goes beyond individual farms towards making the whole food supply chain smart. Logistics and inventory management are better organized with real-time tracking of vehicles, leading to less spoilage and more responsiveness.

Smart contracts are created to automate the processes which in turn reduce the administration burdens and minimize transaction times. The elimination of intermediaries through peer-to-peer transactions can bring about a fair and cost-effective supply chain, which is in turn beneficial for both the farmers and the consumers. Furthermore, literature gives a glimpse of new developments, such as AI, robotics and advanced sensors assimilation. These inventions will, in the long run, make farming more efficient, enable better decision-making, and propel a new era towards farming sustainability and resilience. The critical analysis of existing research gaps reveals the directions for future research efforts that should be addressed by researchers who should, among others, look deeper into some specific applications, explore the methodologies, and the social and ethical implications of this paradigm shift. Finally, the melting point of blockchain and IoT in smart agriculture and food supply chains is not just a technological evolution but a driving force for a systemic change. It is the way to develop the more open, productive and environmentally friendly food system. The way forward entails tackling obstacles, adopting innovation in the technical field, and embracing the different perspectives in order to leverage the full power of IoT integration using blockchain for the improvement of agriculture and food distribution systems.

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