Blockchain-based Food Traceability System for Apulian Marketplace: Enhancing Transparency and Accountability in the Food Supply Chain

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***Abstract*—Traceability is a useful tool for consumers to gather as much information as possible about a particular product. Businesses, on the other hand, see traceability as a strategic marketing tool because it allows them to ensure the quality of their goods to customers in a transparent manner. The ability to readily access all information about an agri-food product is critical to customer trust. Products' information can include where they were manufactured, where they came from, what steps they took to reach at the shelter, and so on. The Blockchain technology is an illustration of how all industries are shifting toward technology and communication. The aim of this paper is to present the Tracecoop project and give an overview of the architecture of the proposed system. The platform ensures trust and guarantees a sense of community both for the consumer and the producer.**

***Index Terms*—Blockchain, traceability, agri-food, supply chain, transparency**

I. Introduction

A Blockchain-based traceability method can boost retailers' impact and trust. Policymakers induced retailers to improve food safety as a result of the incidence of several food scandals in recent years [1]. Blockchain technology enables consumers to track a product's complete life cycle, reducing food fraud. Trust is an important element in interactions between service providers and customers. Trust is an essential driver of patronage intentions in the context of stationary retailing. Convenience, origin, and fairness are the most significant elements influencing consumer decisions [2]. Improved traceability allows for the rapid identification of the point of origin in the event of food poisoning. Of course, food traceability is useful if the data saved in the platform cannot be tampered with or altered [3]–[5]. Blockchain's immutability of data enables it to solve the majority of these problems. Blockchain technologies are trust-proof systems in which non-trusting members can interact with each other in a verifiable manner without the need for a trusted third-party authority.

Blockchain-based traceability systems are currently an interesting topic for researchers [6]–[8]. Authors of paper [9] focus their attention on the need of an agri-food traceability system in supply chains. They develop a system that takes advantage of Radio-Frequency Identification (RFID) devices and use them to track products, notarizing every action in the Blockchain. Such system can enhance the agri-food products safety and quality, but some drawbacks regard the cost of maintaining a Blockchain-based system. The same issue is analyzed in paper [10]. Authors present a Blockchain-based traceability solution for the management of the agri-food sector, using Internet of Things (IoT) devices to gather information from the fields. One of the goals of this research is to compare two different Blockchain, Ethereum and Hyperledger Sawtooth, to understand the pros and cons of each of them. The comparison is focused on

DOI reference number: 10.18293/SEKE23-152

computational costs and performance. Sawtooth results in having better performance in terms of CPU load, network traffic and latency. Other researchers also propose different Blockchain systems, such as the ones based on Hyerledger Fabric [11], [12]. To the best of our knowledge, all proposals lack on a complete evaluation of a supply chain, from the cultivation phase to the selling phase. Moreover, there are no solutions based on using context-aware smart contracts, that can adapt to different scenarios and use cases without the need to modify the built system.

The project's aim is to create a prototype of the TRACE-COOP system by implementing a Blockchain based on the Hyperledger Fabric and Ethereum frameworks to handle information about agricultural supply chain production processes. The tool will provide the final user with instant and comprehensive access to all of the product's properties and characteristics, such as its origin, cultivation, use of chemical substances, organoleptic and nutritional molecular characteristics.

The rest of the paper is organized as follows. Section II gives an overview on Blockchain technology; Section III describes the architecture, Section IV evaluates first results. Finally, Section V draws conclusions.

II. Blockchain

Blockchain is a distributed ledger system that allows for the safe and transparent recording of transactions. It is made up of a network of computers that share a database of events that are organized into blocks and linked together in a chain-like structure. Because each block includes a cryptographic hash of the previous block, it is nearly impossible to change previous transactions without also changing subsequent blocks.

There are three types of Blockchain, named public Blockchain, private Blockchain and consortium or federated Blockchain [13].

- Public Blockchain: there are no nodes that take control of the network; anyone can join the distributed ledger and input or access the information stored in it. A public Blockchain is open and transparent; consensus methods include Proof-of-Work (PoW), Proof-of-Stake (PoS), and Proof-of-Authority (PoA).
- Private Blockchain: managed by a company or individual who gets control of the network. Mining rights can be granted to anyone, but the organization makes the final choice. In this situation, the ledger can be considered more centralized than the public Blockchain because a single entity has more rights than others. A private Blockchain costs less than a public one.
- Consortium Blockchain: the owners of the ledger are multiple nodes. The Blockchain becomes more decentralized than the private one, but not as costly as the public one.

The main Blockchain features are proposed below, to better understand its peculiarities.

- Secure: The Blockchain employs cryptographic techniques to ensure transaction security and integrity.
- Immutable: Once a transaction is logged on the Blockchain, it cannot be changed or deleted without network consensus.
- Distributed: The Blockchain is a decentralized system that uses a network of computers to keep a shared transaction database.
- Trustless: Without the need for intermediaries or trust in a central authority, the Blockchain enables parties to transact with one another.
- Transparent: All transactions on the Blockchain are visible to all network participants.
- Interoperable: Blockchain networks can communicate with one another, allowing value to be transferred between systems.
- Consensus-driven: Changes to the Blockchain must be validated and agreed upon by network members using a consensus method such as proof of work or proof of stake.
- Programmable: Smart contracts enable programmable transactions to be executed automatically when certain conditions on the Blockchain are met.

III. Architecture description

The architecture of the system proposed in the project is shown in Fig. 1. It is composed of four main components: the front-end application for both the consumer and the producer, the private Blockchain for sensors, and the back-end application.

- *Front-end for the consumer*. The front-end component is a web-based application. This app allows the consumer to scan a QR code placed on the products label to access the back-end and read information about the chosen product. The main goal is to guarantee to the consumer that the information shown in the platform are secure and transparent.
- *Front-end for the producer*. The front-end component for the producer lets various actors (i.e., the farmer, the distributor, the retailer) add information not gathered by IoT sensors. In this way, producers can establish a trust relationship with the consumer: the more the consumer trusts a producer, the more he buys that producer products.
- *Private back-end*. Data coming from IoT sensors are not directly inserted in the main back-end [14]; instead, they are gathered in a private local one that is responsible of the collection and conversion of information into value. An edge computing unit reads the information coming from sensors and, after a defined amount of time, extracts valuable information and uploads them into the main back-end [15].
- *Back-end*. This component is in charge of storing information about agri-food products in a safe and immutable way. Data stored in this component are accessible (with readonly permission) from customers who scan the QR code placed on the products label.

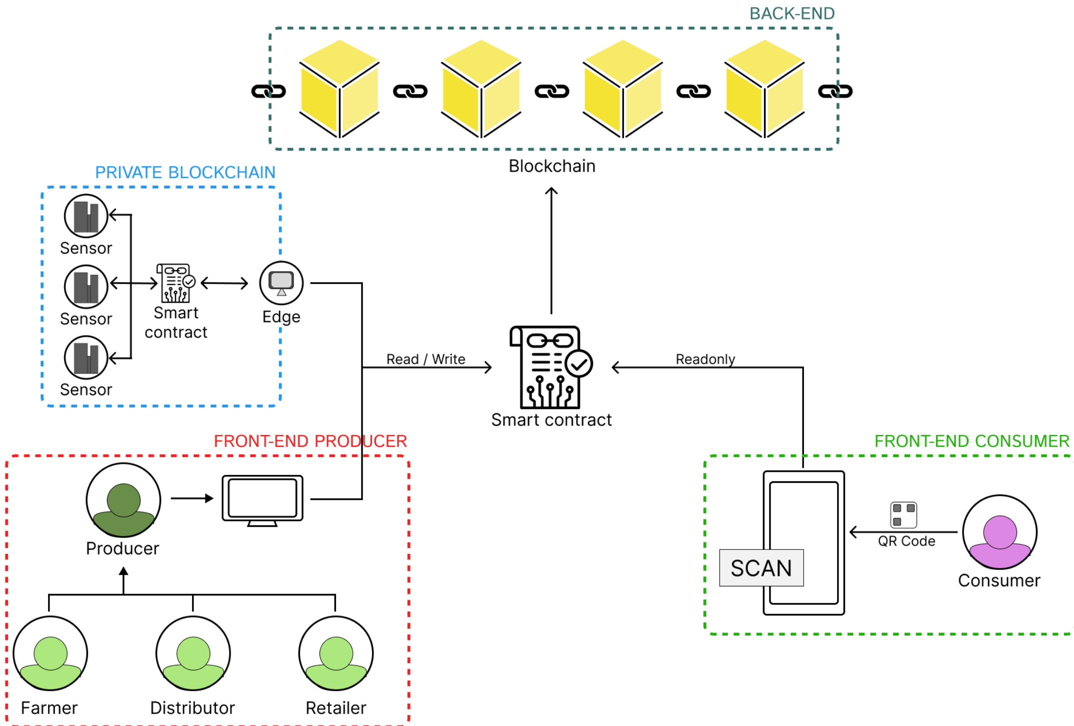

Fig. 1. Architecture of the proposed system

The proposed architecture is the result of the evaluation of some relevant issues:

- The system must be available 24h, being it used in different periods of the day.
- Sensor's data are constantly generated, so the system must support huge amounts of information.
- The system must be scalable and optimized for different kinds of products and not only for the test ones.
- There must be the possibility to add new functions without turning the platform off.

To satisfy the requirements described above, we decided to use a Blockchain-based architecture. Blockchain makes the history of any digital asset unalterable and transparent through the use of decentralization and cryptographic hashing. A Blockchain is a distributed database, shared among network nodes. It stores information electronically in digital representation as a database. Blockchains are best known for their critical position in cryptocurrency systems like Bitcoin, where they keep a secure and decentralized record of transactions. The Blockchain's innovation is that it ensures the fidelity and security of a data record and creates trust without the need for a trusted third party.

IV. Results Evaluation

The performed evaluation has a dual objective, on the producer side and on the consumer side. *Producer side*, the goal is to provide an advantage in terms of economic and organizational benefits: the goal is a) to evaluate the increase in added value, b) to improve the market perception with respect to the Blockchain, and c) to evaluate the increase in company performance. *Consumer side*, a survey has been carried out to allow us to assign a monetary value to the consumer's confidence in the product he is buying, as well as to verify the consumer's propensity to purchase a product if it is tracked using the Blockchain technology.

The applied method allows us to determine the value of the utility deriving from the purchase of an asset through the preferences of individuals regarding the attributes that characterize it. It was decided to set up the work to follow on consumer preferences, focusing our attention on attributes consistent with the technological aspect of the use of the Blockchain and with the information aspects linked to different areas of sustainability. Blockchain technology, in addition to representing an innovative traceability system, can also be understood as an innovative system for communicating with the consumer.

The attributes to identify individuals preferences are:

- Blockchain technology and QR code on the product label (present, absent).
- Information on environmental sustainability (none, partial, complete).
- Information on social sustainability (none, partial, complete).
- Information on products quality (none, partial, complete).
- Information on company innovation (none, partial, complete).

- Price (about half the average price, average price, 4 times the base price, 6 times the base price).

We refer to Choice Experiments (CE) technique [16], [17], that defines two metrics: Utility Function and Willingness To Pay (WTP).

From the point of view of the econometric analysis of data, it is assumed from the theory of consumer behavior that the latter in choosing between two goods will select the one with greater utility. The utility function is described by a deterministic component V, a function of the observable attributes, and a stochastic component ϵ which represents the measurement errors and all the unobservable attributes that influence the purchase decision:

$$U_{n_j} = V_{n_j} + \epsilon_{n_j} \tag{1}$$

$$V_{n_j} = \beta x_{n_j} = \alpha + \beta_{1x_{1_n}} + \beta_{2x_{2_n}} + ... + \beta_{mx_{m_n}} \tag{2}$$

where n denotes the interviewee and j a chosen alternative; with x_{n_j} we indicate the attribute x of the alternative j evaluated by the individual n; β is the weight of the preference for each level of attribute, as well as the compromises in the monetary value, while the coefficient α incorporates the heterogeneity of the sample.

WTP is calculated as the maximum price an individual is willing to pay for a given attribute or characteristic, based on the choices they made during the experiment. In this way, the utility function can be used to calculate the WTP and thus estimate the value that individuals attribute to the different characteristics of the proposed alternatives. WTP formula is:

$$WTP_a = -\beta_a / \beta_p \tag{3}$$

where β represents the specific coefficients estimated for the attribute a and the attribute price p.

The survey has reached a provisional number of participants equal to 327. Experiments are taking advantage of focus groups. This survey is preliminary, however results are good: 59% of the interviewees report a positive WTP with respect to the adoption of Blockchain technology: the WTP has a price of €4.40 and €3.20 for Blockchain technology and quality attributes respectively. Experiments and validation are being performed with further collection of interviews and processing and evaluation of survey results.

V. Conclusion

The TRACECOOP project offers an innovative solution to agri-food traceability, giving producers the possibility to use a Blockchain-based system to ensure data immutability and transparency to customers. The presented project aims at developing a system that is new to market, easy to use both for customers, who do not need to install any application to access the information about the product they are going to buy, and for producers, who can easily gather information from fields using IoT sensors, convert them into valuable information and upload them into a public Blockchain as Ethereum. Some preliminary results show the importance of applying such architecture to the agri-food supply chain: consumers are more likely to trust a product whose traceability in stored in a Blockchain platform. The platform can be extended to be part of a more complete smart city based on Blockchain technology [18]. We are currently performing extensive experiments to provide a comprehensive overview of the market.

Acknowledgment

The authors would like to thank the TRACECOOP project.

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