BlueBio SMARTCHAIN Project

Architecture of traceability system

Research Findings Brief

September 2024

Blockchain networks

Blockchain-based traceability integrated with IoT can provide benefits and advantages over traditional traceability systems, such as improved and fine-grain traceability, tamper-proof data, real-time and transparent data sharing, automated compliance to regulatory requirements, and efficient and targeted recall

This research finding brief summarizes the SMARTCHAIN´s project work on the specifications for a blockchain-based traceability system for use in the seafood supply chains. The motivation for such a system is to improve transparency, circularity, and sustainability. The focus is on data modelling using Unified Modelling Language (UML) 2.0 diagrams and using these as the basis for requirements specifications for a blockchain-based traceability system designed to ensure an unbroken cold chain.

Blockchain is a decentralized, distributed ledger technology that has been applied in many domains and applications. Blockchain networks can be categorized into permissionless and permissioned depending on who can access the network, or classified as public, private or consortium according to how the permissions to write to blockchain are assigned[1]. Hybrid blockchains combine private and public blockchain and allow organizations to control what data can be publicly accessible and what is restricted, as well as who can access the restricted data. In hybrid blockchains, confidential information is protected but verifiable when needed. Consortium blockchains have been widely used in supply chain applications.

Requirements and specifications

High-level requirements and system functionality specification have been defined and a high-level system architecture is proposed to facilitate data sharing along the seafood supply chain and the end-to-end traceability

High level architecture for a blockchain-based traceability system for the seafood supply chain

The input to the requirement analysis consists of; i) *Regulatory requirements* for example, traceability requirements from the food law (EU regulation No. 178/2002) ~~is~~ based on the "one step forward, one step back" paradigm. Blockchain can enable even stronger end-to-end traceability to guarantee an unbroken cold chain; ii) *Literature review* of a number of technical systems published, for instance, user requirements in a similar context are documented by Jiang *et al.* (2022) [2]; iii) *Experience and knowledge* from previous project work regarding requirements, architecture and system design. Furthermore, the data models are based on interviews and a literature study related to the fishery and aquaculture industry (as documented in SMARTCHAIN Deliverable 1.3). The models are extensible and have been generalized from industrial practices in Norway and Iceland. *The following functionality requirements have been identified*:

- Data & storage management: data collection (manually via GUI & automatically via API); uploading to blockchain; query data from blockchain; off-chain data management (various types of data should be supported, e.g., timeseries, text documents, images, videos).

[1] Cao, B. *et al.*, "When Internet of Things Meets Blockchain: Challenges in Distributed Consensus," *IEEE Netw.*, vol. 33, pp. 133–139, 2019

[2] Jiang, S. and Ræder, T. B. (2022) "Experience on Using ArchiMate Models for Modelling Blockchain-Enhanced Value Chains," in *The International Conference on Evaluation and Assessment in Software Engineering 2022*, Gothenburg Sweden: ACM, Jun. 2022, pp. 375–382. doi: 10.1145/3530019.3531346

High level architecture

The design of the traceability system architecture supporting the functional requirements and specifications, is structured into layers. The main components in each layer are identified and their role and interaction described

- User and access management: generation of unique user IDs; add/delete user; assign roles to users and their associated access rights to data (all data in blockchain is transparent to all participants, but off-chain data may have restrictions).
- Creating links with on-chain data (verifiable using hash codes).
- User/client interaction via an interactive interface, for functions such as showing traceability, product tracking etc.
- Integration with stakeholder ERP systems for automatic data exchange.
- Trace: query & show the history of identifiable/traceable events and state changes (if possible/relevant).
- Generation of traceability QR codes for traceability.
- Track: query & show the status of any product/asset.
- Monitor & alert: monitor the condition and flow of the product/fish along the supply chain and give alerts when abnormalities occur, e.g., if temperature exceeds some limit.

As inspiration for this we have used the architecture of a blockchain-based agri-food traceability designed by Feng *et al*., (2020)[3] and of a food safety system designed by Lin *et al*. (2019)[4]. At the technical level, these have much in common with seafood supply chains. Based on these, we propose a high-level architecture for a blockchain-based traceability system for seafood supply chains based on four layers as illustrated in Figure 1 below.

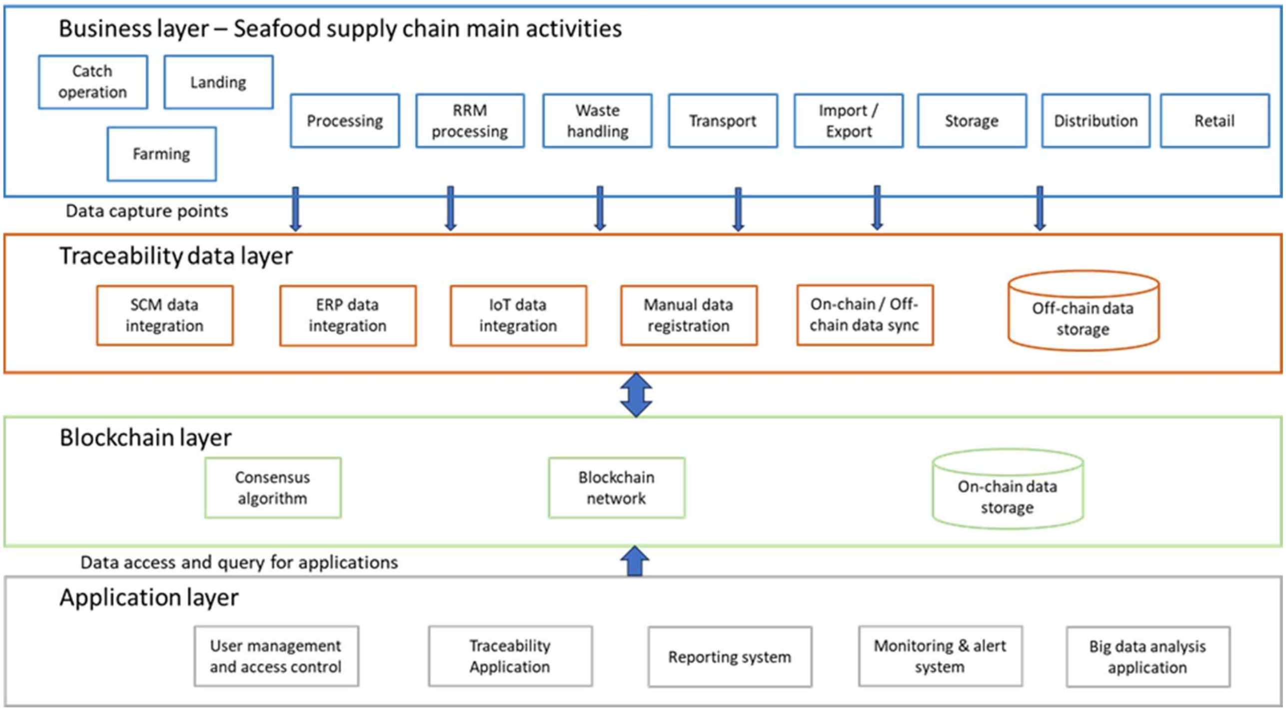

Figure 1 High level architecture of blockchain-based traceability system for seafood supply chain (from Deliverable 4.1)

The Business layer represents the business activities of stakeholders/actors involved in the whole supply chain from fish catch operation (for fishery) or farming/harvest (for aquaculture) through processing and waste handling to distribution and retail. Key data capture points are identified and associated data to be recorded are modelled in the data models.

[3] Feng, H., *et al.*, "Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges," *J. Clean. Prod.*, vol. 260, 2020, doi: 10.1016/j.jclepro.2020.121031.
[4] Lin, Q., *et al.*, "Food safety traceability system based on blockchain and EPCIS," *IEEE Access*, vol. 7, pp. 20698–20707, 2019.

Traceability data

Data are linked to Traceable Units and traceability events and collected at data capture points. These data give information related to seafood quality, temperature, humidity, freshness, traceability, sustainability and circularity. The data can be collected automatically through connected IoT devices and sensors, integration of existing business systems (e.g., SCM, ERP) or data can be registered manually

The Traceability data layer represents the collection and storage of the traceability/key data as well as communication with blockchain. Each actor can store the traceability data collected using an off-chain data storage locally or in the cloud. Key traceability data with a hash representing the stored data associated with the traceability event will be uploaded to the blockchain (on-chain data storage).

The On-chain/Off-chain data sync component is used to synchronize data between on-chain and off-chain data storage and links the data layer and the blockchain layer. This component extracts key traceability data to be uploaded to the blockchain from the off-chain data storage, generates a hash associated to it and the transaction to be uploaded, and uploads the data to the blockchain. The hash and the reference to the on-chain data is also stored on the off-chain storage for future query and also used to guarantee data integrity. When data is queried via the blockchain, relevant off-chain data storage containing the data is identified and the associated data is retrieved and verified against the hash to ensure that the data is not tampered.

The Blockchain layer facilitates traceability information transparency and improves the security of seafood traceability. Based on the quality data collected from the data layer, smart contracts of blockchain can be used for real-time quality monitoring and control, satisfying the requirements of accountability and traceability. The key components in this layer consist of consensus algorithms, distributed blockchain network and on-chain data storage (the distributed ledger).

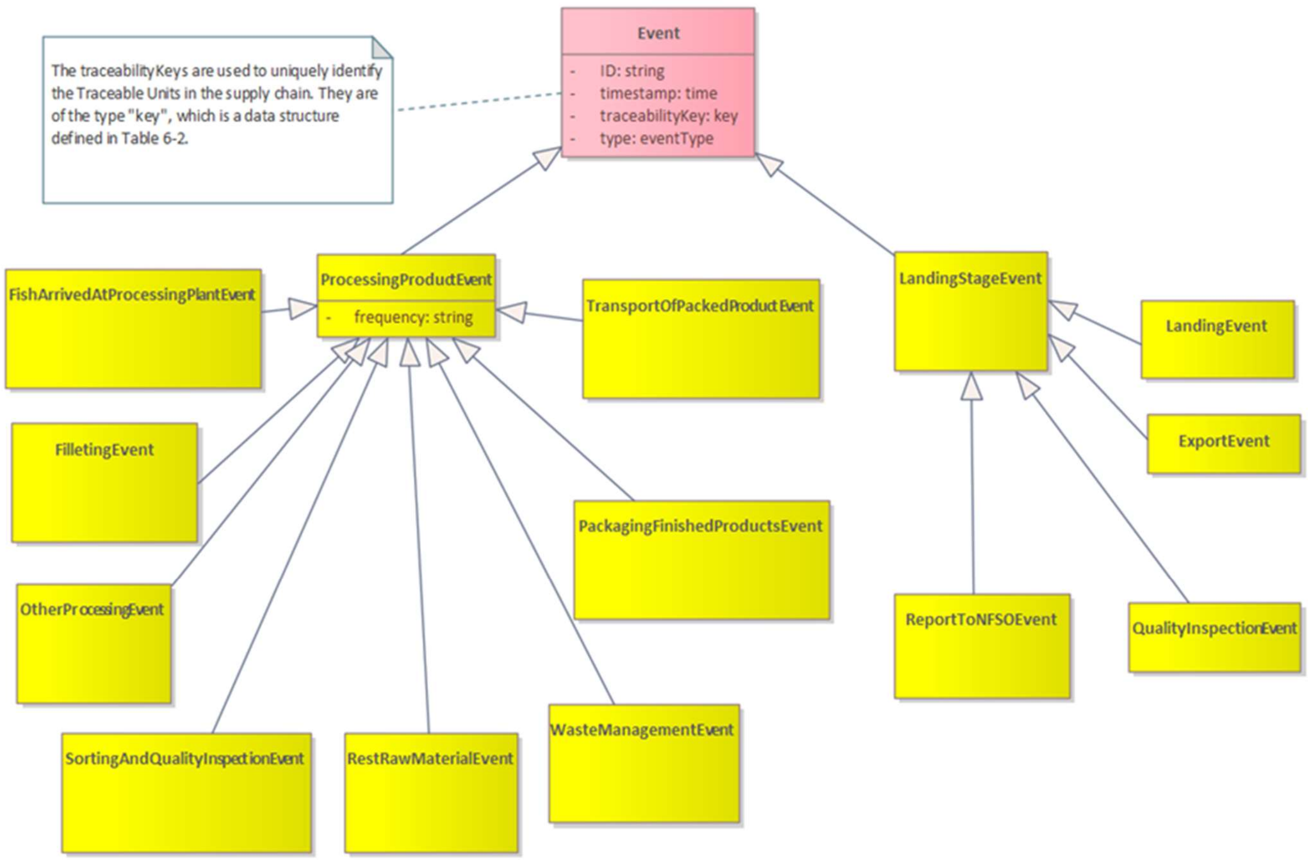

Figure 2 Information model based on events for the traceability system (from Deliverable 4.1)

The Application layer consists of various applications that utilize the data collected in the traceability system through the blockchain. Actors in the traceability chain can view the data records (events) along the whole supply chain processes, perform "track and trace" functionality and big data analysis, and facilitate reporting to the authorities. The

Track and trace

The "track and trace" functionality consists of asset management (including definition of Traceable Units) and traceability queries.

QR codes for traceable units

We propose to use QR codes (traceability code) to identify the lowest level of Traceable Units (TRU), such as at pallet level. QR code can be generated for each pallet of fish at the landing stage and attached to the pallet so that the QR code can be used to automatically identify the pallet and collect traceability information along the supply chain, as long as the pallet of fish stays together

Generalized model

The data modelling is generalized from data surveys and analysis based on interviews with several key stakeholders in Norway and Iceland, covering supply chain stages related to fishery (catch operation and landing), aquaculture (farming), primary processing and rest raw material processing.

real-time IoT data collected can facilitate the monitoring of the supply chain and can provide timely alerts utilizing smart contracts when deviation occurs. Furthermore, the user management and access control module provides functionality for managing user roles and their access rights to the specific data stored in the traceability system. In addition, the access control module allows the actors to define what data they possess can be visible to whom. For example, end consumers may be only interested to see the origin of the product and get a confirmation that the product is handled properly along the supply chain, and do not care about the details about how the product is transported, while a distributor may also want to know the details of the logistics and other parameters regarding the product quality, and a processor may only share production details with certain actors under specific terms.

The on-chain data storage module will register traceability event IDs, timestamps and hash values. Relevant key data, such as the traceability key, can also be stored on-chain.

An authorized user can add seafood product information to the system. Users can also manually register traceability events and associated data via the user interface. Traceability can be done at various levels of granularity e.g., at product, batch, pallet or fish level. Users can scan the QR code to enter new data for specific TRU (pallet) and new data collected from sensors can be automatically attached to this TRU via the QR code along the supply chain. When new TRUs are created later, new QR code will be created and attached to the TRU to link relevant data to the TRU.

When users want to track and trace a seafood product, they scan the QR code attached to the TRU. The blockchain will identify the TRU and query all the associated traceability data. The hashes and traceability keys stored on-chain will be used to query off-chain data and verify off-chain data integrity. The verified data can then be returned to the application according to the access control rules so that users can view the associated traceability information that they are authorized to access.

We focus on traceability keys associated with Traceable Units in this report. Traceability codes can be generated for these traceability keys as used in the literature and existing traceability system practices, e.g., a UUID. The primary motivation for this is to be able to uniquely identify the Traceable Units.

Data models of a blockchain-based traceability system

The SMARTCHAIN work focused on data modelling regarding what traceability data shall be gathered at which point and on which level (batch, pallet, product, fish, etc.) in the supply chain and the relationship between data and data sources (see Figure 2). In addition, event types defined in the EPC networks can be considered and integrated in the data model. Requirements on new types of data to be recorded in the system are becoming increasingly common, for example, to include sustainability information in the traceability system to facilitate the assessment of the sustainability of supply chains and products, and to include circularity information in the system with the increasing interest in the circular economy.

End to end traceability

The current data models are limited to details from the primary stages of the seafood supply chains.
To support full end-to-end traceability, more events need to be included in the data model, e.g., activities related to logistics/transport, customs, importer/exporter, distribution and storage

Limitations and Recommendations

Traceability keys for traceable units have been identified in the proposed data models. Globally unique IDs for traceable units, e.g., based on emerging standards, can be generated to facilitate end-to-end traceability.

To ensure end-to-end traceability, changes are needed in current supply chain practices. For example, some of the data required for traceability is not mandatory in current regulations. The collection and sharing of all (as much as possible) traceability information is key for true end-to-end traceability.

In addition, some processors mix fish from different suppliers/vessels into one batch, which breaks the end-to-end traceability as it is not possible to trace back from which supplier a fish from a batch comes from. To ensure finer grain traceability, one-to-one mapping between catches and batches should be ensured.

Key sources for further information

This work has been carried out by SINTEF Digital. Further information on the research presented in this brief, please contact: Shanshan Jiang, e-mail: shanshan.jiang@sintef.no

Deliverable

Jiang, S., Gorman, J. (2023). Architecture of traceability system. The SMARTCHAIN project co-funded by ERA-NET, EU Horizon 2020 G.A. No 817992, and Norges forskningsråd (RCN), Innovation Fund Denmark (IDF), and The Icelandic Centre for Research (RANNIS) / Technical Development Fund (TDF). Deliverable: D4.1, SINTEF Digital, Trondheim, 37 pages.

SMARTCHAIN – Smart solutions for advancing supply systems in blue bioeconomy value chains

https://bluebioeconomy.eu/smart-solutions-for-advancing-supply-systems-in-blue-bioeconomy-value-chains/
https://www.sintef.no/en/projects/2021/smartchain/

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