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Abstract. Business-to-Business (B2B) enterprise systems and services have become increasingly important for Small and Medium Enterprises (SMEs) over the last few years. Their major potential is observable in the massive reduction of business transaction costs and enhanced cross-sectoral collaboration. A successful B2B marketplace should ensure greater transparency and trust while performing business processes. Among different ways to build transparency and trust, IoT-based traceability system can enable partners to track products and monitor the quality of production processes. Partners can principally trust each other and can avoid fraudulent malpractices. It is, however, still insufficient to prevent fraud and fight against counterfeit and inferior products due to data manipulation. Blockchain technology is a promising technology to prevent fraud through its data immutability characteristic. However, the adoption of Blockchain technology in IoT-based traceability system for SMEs entails significant challenges. For example, the transition of a large volume of IoT data from company-owned databases to Blockchain network would require a significant shift in terms of IT infrastructure. This paper discusses the typical challenges and presents an approach to handle them. It can be helpful to pave the way to support SMEs adopt Blockchain technology in IoT-based traceability system.

Keywords: IoT, Sensors, Traceability, Blockchain, Multi-sided Platforms

1 Introduction

In many industries, the basis of value creation depends on a complex network of organizations that share or exchange information, services, and goods. They use information and communication technologies to manage these processes efficiently with minimum costs. Digital business-to-business (B2B) platforms are one of the recent vital topics in this field. These platforms focus on different domains, such as manufacturing, logistics, smart cities, and e-commerce for data, services, and products[1].

NIMBLE [2] is a multi-sided, federated, digital platform with a B2B marketplace for products and services. Its source-code is under a permissive license, which allows third parties to use it for any purpose. One of its fundamental business requirements is that buyers want to access recent and precise information about their ordered products. This information includes, for instance, current and past locations, and product-related events. The location information helps the buyer to schedule activities accurately, which can reduce the cost of idle times and re-planning. An example of a relevant event is the exposure to contractually defined environmental conditions, such as temperatures above 0° Celsius. Often such environmental conditions require an Internet of Things (IoT) application where products and locations contain sensors. A benefit of IoT information is that it can support employees in the identification of product quality problems, responsibilities in warranty cases, and plagiarism. Tracking and Tracing (T&T) are software functions that meet the requirements as mentioned earlier.

Typically, a service provider is responsible for the T&T information of the supply chain partners. The latter have to trust the provider that the information is accurate and securely stored. In today's global supply chains, this trust is not always a prerequisite. New data storage technologies, such as Blockchain, address the trust and the security issue. Several activities currently focus on the development and demonstration of T&T solutions with Blockchain technology like OriginTrail [3], Ambrosus [4].

This paper presents an architecture for a T&T solution that merges IoT and Blockchain and integrates it in a digital B2B platform. This architecture is the basis of the T&T solution implemented and tested in the NIMBLE platform. Its source code is available on GitHub [5].

The paper structure is as follows: Section 2 illustrates concisely a practical Use Case Scenario and some challenges that scenario faces. Section 3 provides a brief overview of the technologies and related works of Blockchain and IoT-related tracing in the research paradigm. Section 4 proposes an approach to the challenges mentioned in Section 2. The paper ends with concluding remarks in Section 5.

2 Use Case and Challenges

A use case helps researchers to identify problems worth of research to evaluate the results. The latter is especially important if the research focuses on technology application. The authors identified a use case for these purposes. It relies on the production and logistics processes of two real companies from the construction industry. The factories are in northern Europe and experience temperatures below -30° C during winters. The focused product is a composite structure used within construction. Intense changes in temperature and humidity can damage its strength leading to failure during operations and may lead to high warranty claims. The producer of the structure has to monitor the production and storage environment for this particular reason. Fig. 1 illustrates an overview of a production scenario for the producer of the composite structure.

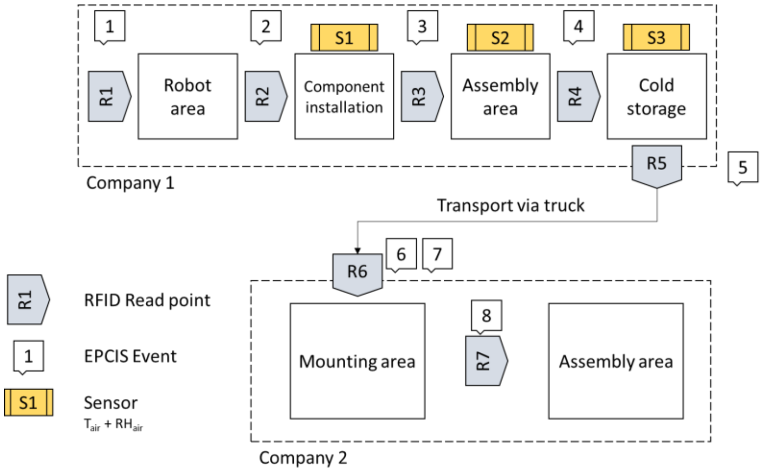

Fig. 1. Production scenario for a composite structure and logistics overview

Company 1 is the supplier of the composite structure, and company 2 is the customer that mounts it in a larger product. The companies have separate factories at different locations. They use trucks to transport the structures from one factory to the other. The test implementation focuses on the first company. Its production has four steps that require tracking. It begins with a robot work area and ends with cold storage outside the factory. RFID readers monitor the entrance/exit of each area. Temperature and humidity sensors monitor the environment of steps two, three, and four.

These two companies can trust each other. However, adequate trust is not always present between company 1 and other customer companies. Through its immutable and irrevocable properties, a Blockchain solution is increasingly prominent for trust; however, challenges in adopting Blockchain within the IoT-based product traceability system still exist. The authors identify three significant challenges standing in the way:

- **Flexible usage of Blockchain technologies**: Blockchain represents a significant advancement in technological innovation that facilitates consensus within a trustless environment. However, Blockchain does not always make sense in different application scenarios [6]. For instance, when all supply chain partners can trust each other, it is not necessary to adopt Blockchain technologies. Traceability system should allow companies to choose whether and which type of Blockchain to use, according to the requirements of specific application scenarios.
- **Infrastructural transition to Blockchain technologies**: The transition from the world of company-owned databases to Blockchain network would require a significant shift in terms of IT infrastructure. Furthermore, companies may have worries, for instance, loss of control of their data, and exposure of sensitive production data during this transition phase.
- **A large volume of IoT data**: Companies can capture an enormous amount of IoT data in the production processes for traceability and quality monitoring. This IoT

data include, for instance, EPCIS events, and various sensor data. For quality assurance, interest from customer companies is not only the sensor data at the specific time of the EPCIS event occurrence but also sensor data in the period between EPCIS events. In the use case scenario, temperature and humidity sensors monitor the environment of steps two, three, and four. If one considers a sensor that measures the temperature and humidity every one second, then for a single hour, there will be 2 x 3600 total measurements. When a product stays in "cold storage" in step four for one single day, the relevant number of measurements will range 2 x 24 x 3600 measurements. It is a significant challenge to put this large volume of IoT data into Blockchain at reasonable scalability and cost, taking into account the storage volume in each Blockchain transaction, transaction fee, and transaction rates.

3 Background and Related Works

3.1 IoT-based Product Traceability

Increasing competition for similar products in the present day markets requires the manufacturers' attention and awareness regarding each stage a product goes through during the supply chain and manufacturing process. The emphasis lays on the fact that by tracking the events of the products under consideration helps improve the quality and determine any faults or error that might occur. Tracking and Tracing systems widely use the EPCglobal and EPCIS from the GS1[7]. Representation of physical products in a digital form is achievable by using EPCglobal. EPCglobal provides a method to identify physical products through unique codes. EPCIS provides a method to acquire the events for the products and allows sharing this event information in an interoperable manner. The identification of the products occurs by scanning the RFID tags via dedicated RFID scanners. An event capturing mechanism provides all other necessary filterings of the data generated from the readers, and finally, a dedicated EPCIS server stores the event-based information. Byun and Kim [8] provide an open source platform, namely Oliot EPCIS, which provides a base for experimentation with sensors along with the integration of EPCIS standard.

With the rapid growth in the IoT sector, metadata like environmental parameters of the events the product experiences within the processes could be captured via constrained sensor and actuator nodes and provide deep insight on factors that might affect the quality of the product at present or for later purposes. IoT within the supply chain as well as manufacturing processes opens a new paradigm of integrating ICT-based intelligence, in turn opening the prospect of Smart Products. Such additional information enhances the possibility to trace reasons for product failures or defects and help manufacturers pinpoint the root cause. Work presented by Woo et al. [9] provides an approach to integrate IoT information from cars into the EPCIS structure. They extend the EPCIS structure using the *Extension* field to add relevant automobile information like RPM, braking, steering wheel data, GPS locations at the particular instance of the event when the car is driven. Based on different events like 'Repairing,' 'Scrapping,' the authors use geo-locations using a GPS module to add extensions to the various Events. The solution from the authors sends information periodically to an EPCIS server in the form of XML documents and use the information to provide tracking and tracing solution for connected cars. Authors of Oliot EPCIS [8] validate the platform by conducting experiments in the healthcare sector. They measure medical sensor values via using Bluetooth (BLE) along with another IoT standard Constrained Application Protocol (CoAP) and generate events based on the sensor data capture. Alfian et al. [10] provide a food traceability system for Kimchi supply chain in Korea which amalgamates RFID system for product identification, wireless sensor networks (WSN) for environmental condition monitoring and data mining on the data collection for the estimation of missing sensor data during wireless transmission within the supply chain.

Works presented by authors in [8-10] manifest strong efforts of inculcating IoT into standard product traceability within different sectors like healthcare, automobile, and food and emphasis of their work improves upon the overall understanding of product quality within standard supply chains.

3.2 Blockchain and Traceability Systems

Blockchain could provide essential features such as assurance of the product genuineness as well as transparency within the supply and manufacturing chains. There are already practical efforts to use EPCIS information from products with Blockchain, as well as IoT information. OriginTrail provides an IT solution to decentralize supply chains using Blockchains. OriginTrail [3] leverages the EPCIS framework for data interoperability among different organization within the supply chains. It also incorporates the WoT (Web of Things) Framework [11] for IoT sensor data by W3C. IoTeX [12] is another solution, which provides a Blockchain powered for IoT information. It leverages the concept of “Blockchains in Blockchains” where multiple private Blockchains termed as “subchain” interact with IoT devices and these “sub-chains” interact to a public Blockchain (rootchain). The concept provides a form of abstraction to the public Blockchain and the IoT devices. These solutions can only guarantee limited flexibility on the use of Blockchain technologies and cannot easily validate the large-volume relevant sensor data in the tracking process.

Figorilli et al. [13] provide a prototype Blockchain implementation of chestnut boards traceability within the lumbering industry. The authors use RFID systems alongside QR codes and Android mobile applications for tracing lumber products within the supply chain and use well-known Ethereum [14] Blockchain solution for more transparency within supply chains. Tian [15] illustrates a traceability system in the food supply chain for tracking real-time product information using Blockchain, IoT based on Hazard Analysis and Critical Control Points (HACCP). The work describes the usage of decentralized databases to store information, right from the harvested crop plants via RFID tags all the to the retailers and controlling authorities, subsequently enabling transparency and collaboration via Blockchain based solution. Hepp et al. in their novel approach [16] are already addressing issues of securing physical products to Blockchain by using varnishes that produce a unique crack pattern that cannot be replicated or cloned on inferior products.

4 Approach

Fig. 2 illustrates the architecture proposed in this study. It integrates Blockchain technologies as a value-added service in the traceability system. The bottom part of the figure is the infrastructure of an example supply chain. Each company in the supply chain has its local infrastructure for the management of traceability relevant IoT data. Besides an EPCIS data repository, it uses a separate time series database for the management sensor data. Based on the time series databases, companies can realize visualization and monitoring of the collected sensor data. When companies have no requirements on the usage of Blockchain for specific production orders, they can keep all traceability data in their infrastructures. In the case of Blockchain, it is necessary for the reason of, for instance, fraud prevention, that companies send traceability data of relevant production orders into Blockchain through additional value-added APIs.

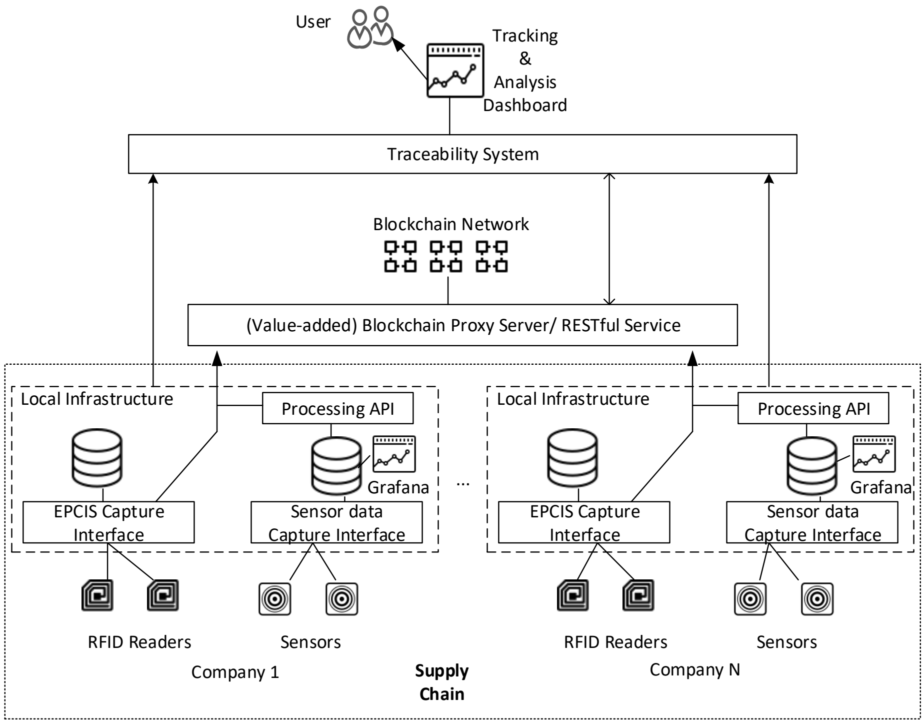

Fig. 2. Architecture of IoT-based Product Tracking with Blockchain as a value-added service

When companies choose to use Blockchain Services, it is only mandatory to send cryptographic-hash rather than raw traceability data into Blockchain. On the generation of cryptographic-hash for traceability data, the authors adapt ideas from Traceable resource unit (TRU). TRU is a unique identification of the resource representation with similar characteristics that must be traceable [17]. It can have different granularity levels, for instance, single product item, or a batch or product items. In this study, the

Traceable Data Unit (TDU) is defined as a unit of data representation that should be traceable and verifiable. Users can define different granularity levels of TDU for EPCIS data and sensor data. For EPCIS data, the authors, take every single EPCIS event as a TDU and generate a cryptographic-hash for each EPCIS event. On the tracking and tracing process, users can retrieve the EPCIS events from data storage of supply chain partners, and then generate cryptographic-hash and verify the validity of the retrieved EPCIS events with Blockchain. For sensor data, users can verify the validity of sensor data as well based on the defined TDU, with the cryptographic-hash stored in the Blockchain. For example, it is possible to define sensor data in one hour starting from every hour exactly (e.g., from 9:00 sharp to 10:00 sharp) as a TDU. Assume a product has been in a storage area for 1 hour from 01:20 to 02:20, users only need to calculate the cryptographic-hash for the batch of sensor data from two TDUs (i.e., from 01:00 to 02:00 and from 02:00 to 03:00). They can then check the existence of calculated cryptographic-hash in Blockchain to verify the correctness of the retrieved sensor data. This kind of validation with Blockchain can ensure that supply chain partners have not manipulated or tampered the traceability data in their local storages.

5 Conclusions

In this work, the authors have proposed an architecture that integrates Blockchain technologies as value-added services in IoT-based Product T&T solution. This architecture is the basis of the T&T solution implemented and tested in a digital B2B platform, i.e., NIMBLE platform. It takes Blockchain technology as an optional value-added service to address trust and security issues. Companies, i.e., SMEs, can choose whether to use Blockchain services, according to requirements of their specific application scenarios. This architecture introduces the concept of Traceable Data Unit to handle large-volume of IoT data, SMEs can define different granularity levels on the traceable data unit and sends only cryptographic-hash of each Traceable Data Unit rather than raw IoT data into Blockchain networks. With this approach, SMEs have total control of their data and can benefit from the immutable and irrevocable properties of Blockchain with flexible scalability and cost.

Nonetheless, this approach is still a work in progress. As future work, the authors are seeking to address online product quality monitoring and quality assurance with smart contracts in Blockchain. Another limitation of this research is the risk of inaccurate data in Blockchain. Blockchain technology can help to prevent data tampering for the data stored in Blockchain, but cannot avoid the situation that companies send incorrect data, e.g., sensor data into Blockchain.

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References

1. Petersen, K. J., Ogden, J. A., Carter, P.L.: B2B e-marketplaces: a typology by functionality, International Journal of Physical Distribution & Logistics Management, Vol. 37 Issue: 1, pp.4-18 (2007). doi: 10.1108/09600030710723291
2. Innerbichler, J., Gonul, S., Damjanovic-Behrendt, V., Mandler, B., Strohmeier, F.: NIMBLE collaborative platform: Microservice architectural approach to federated IoT, 2017 Global Internet of Things Summit (GIoTS), Geneva, pp. 1-6 (2017). doi: 10.1109/GIOTS.2017.8016216
3. Rakic, B., Levak, T., Drev, Z., Savic, S., Veljkovic, A.: Origin Trail White Paper. Available Online: https://origintrail.io/storage/documents/OriginTrail-White-Paper.pdf, Last Accessed: 2019/03/24.
4. Ambrosus Website, https://ambrosus.com/, Last Accessed: 2019/04/02.
5. NIMBLE-Platform GitHub Organization. Online: https://github.com/nimble-platform
6. Wüst, K., Gervais, A.: Do you need a Blockchain? In: Crypto Valley Conference on Blockchain Technology (CVCBT), Zug. pp. 45-54 (2018). doi: 10.1109/CVCBT.2018.00011
7. EPC Information Services (EPCIS) Release 1.2 Ratified Standard. GS1. https://www.gs1.org/sites/default/files/docs/epc/EPCIS-Standard-1.2-r-2016-09-29.pdf, Last Accessed: 2019/03/31.
8. Byun, J., Kim, D.: Oliot EPCIS: New EPC information service and challenges towards the Internet of Things, *2015 IEEE International Conference on RFID (RFID)*, San Diego, CA, pp. 70-77 (2015). doi: 10.1109/RFID.2015.7113075
9. Woo, C., Jung, J., Euitack, J., Lee, J., Kwon, J., Kim, D.: Internet of Things platform and services for connected cars. In: IoTBD pp. 469-478 (2018). doi: 10.5220/0005952904690478
10. Alfian, G., Rhee, J., Ahn, H., Lee, J., Farooq, U., Ijaz, M.F., Syaekhoni, M.A.: Integration of RFID, wireless sensor networks, and data mining in an e-pedigree food traceability system. Journal of Food Engineering, 212, pp.65-75. (2017). doi: 10.1016/j.jfoodeng.2017.05.008
11. Trifa, V., Guinard, D., Carrera, D.: Web Thing Model. W3C Member Submission. Available Online: http://model.webofthings.io/, Last Accessed: 2019/04/04.
12. IoTeX White Paper v1.5. Available Online: https://iotex.io/white-paper. Last Accessed: 2019/03/25.
13. Figorilli, S., Antonucci, F., Costa, C., Pallottino, F., Raso, L., Castiglione, M., Pinci, E., Del Vecchio, D., Colle, G., Proto, A., Sperandio, G.: A Blockchain implementation prototype for the electronic open source traceability of wood along the whole supply chain. *Sensors*, *18*(9), p.3133 (2018). doi: 10.1016/j.ijinfomgt.2019.05.002
14. Buterin, V.: Ethereum White Paper (2017).
15. Feng Tian: A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things. In: *2017 International Conference on Service Systems and Service Management*, Dalian, 2017, pp. 1-6 (2017). doi: 10.1109/ICSSSM.2017.7996119
16. Hepp, T., Wortner, P., Schönhals, A., Gipp, B.: Securing physical assets on the blockchain: Linking a novel object identification concept with distributed ledgers. In: *Proceedings of the 1st Workshop on Cryptocurrencies and Blockchains for Distributed Systems* (pp. 60-65) ACM. (2018). doi: 10.1145/3211933.3211944
17. Kim, H.M., Fox, M.S., Gruninger, M.: An ontology of quality for enterprise modeling. In: Proceedings 4th IEEE Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET ICE'95) pp. 105-116. IEEE (1995). doi: 10.1109/ENABL.1995.484554