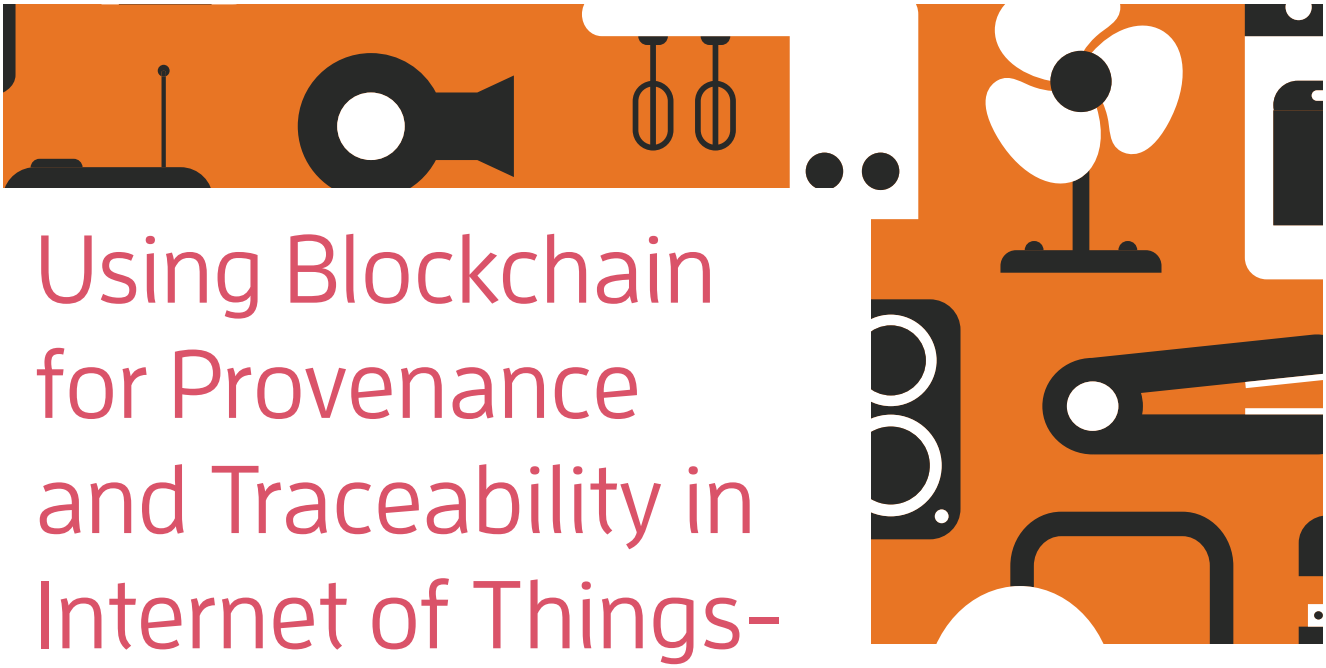

Using Blockchain for Provenance and Traceability in Internet of Things–Integrated Food Logistics

Amitangshu Pal and Krishna Kant, Temple University

Provenance and traceability are crucial in the food distribution and transportation network for ensuring integrity of food labeling and efficient management of quality and contamination issues. Significant issues in terms of cost, quality, and health issues can result without sufficient visibility. This article elaborates on the use of emerging blockchain technology to improve Internet of Things–enabled food logistics.

Digital Object Identifier 10.1109/MC.2019.2942111
Date of current version: 22 November 2019

Transparency, traceability, and provenance are essential components of food logistics and becoming ever more important with advancing globalization and food technologies. Simply stated, wholesalers, retailers, and consumers want to know where their food came from, what intermediate parties/processing it went through, whether they can trust the labeling, and, in the case of food-borne disease outbreak, where the tainted food originated.

Fresh food is both perishable and easily contaminated and responsible for much of food-borne illnesses (popularly called "food poisoning"). Extensive data from the Centers for Disease Control state that, each year, roughly one in six Americans (or 48 million people) get sick, 128,000 are hospitalized, and 3,000 die from foodborne disease. As a concrete example, the 2011 *Listeriosis* cantaloupe outbreak affected 28 states, which led to 143 hospitalizations and 33 deaths. Due to the lack of provenance information, the origin of such outbreaks cannot be identified accurately and quickly, leading to larger

 0018-9162/19©2019IEEE

EDITOR **TREVOR PERING**
Google; peringknife@google.com

FROM THE EDITOR

The technologies of the Internet of Things inherently merge the physical and virtual worlds, constantly raising new challenges as the practical realities of atoms are manifested as bits. This article explores how the nascent blockchain technology can be applied to maintain an accurate and authoritative picture of physical happenings, without relying on an ever-connected centralized authority. Specifically targeting food distribution logistics, this perspective addresses a significant problem that touches an extensive global ecosystem. — *Trevor Pering*

health impacts and throwing away substantial amounts of perfectly good food.

Another challenge in the current supply chain is its dismal efficiency of 10–20%[1] in spite of significant food spoilage/waste. The latter is estimated to be about 12% in the supply chain itself[2] but could be higher due to further discarding by the retailer or consumer. Both of these issues can be tackled with an Internet of Things (IoT)-based monitoring of all stages of food logistics (including harvesting, processing, wholesale distribution, and retailing), thereby making the pickup, transportation, storage, and delivery much more agile and in tune with supply, demand, and quality changes with time.

Standardized labeling/addressing of all-important elements in the logistics is key to its automation. In this regard, a comprehensive set of standards known as GS1 have been developed that identify products via a unique Global Trade Item Number (GTIN) and facilities via a unique Global Location Number. GTINs with extended data, such as batch or lot numbers, are printed on the pallets and cases. Figure 1 shows an example of case- and pallet-level identification by the harvesters, manufacturers, and shippers. These standards are being rapidly

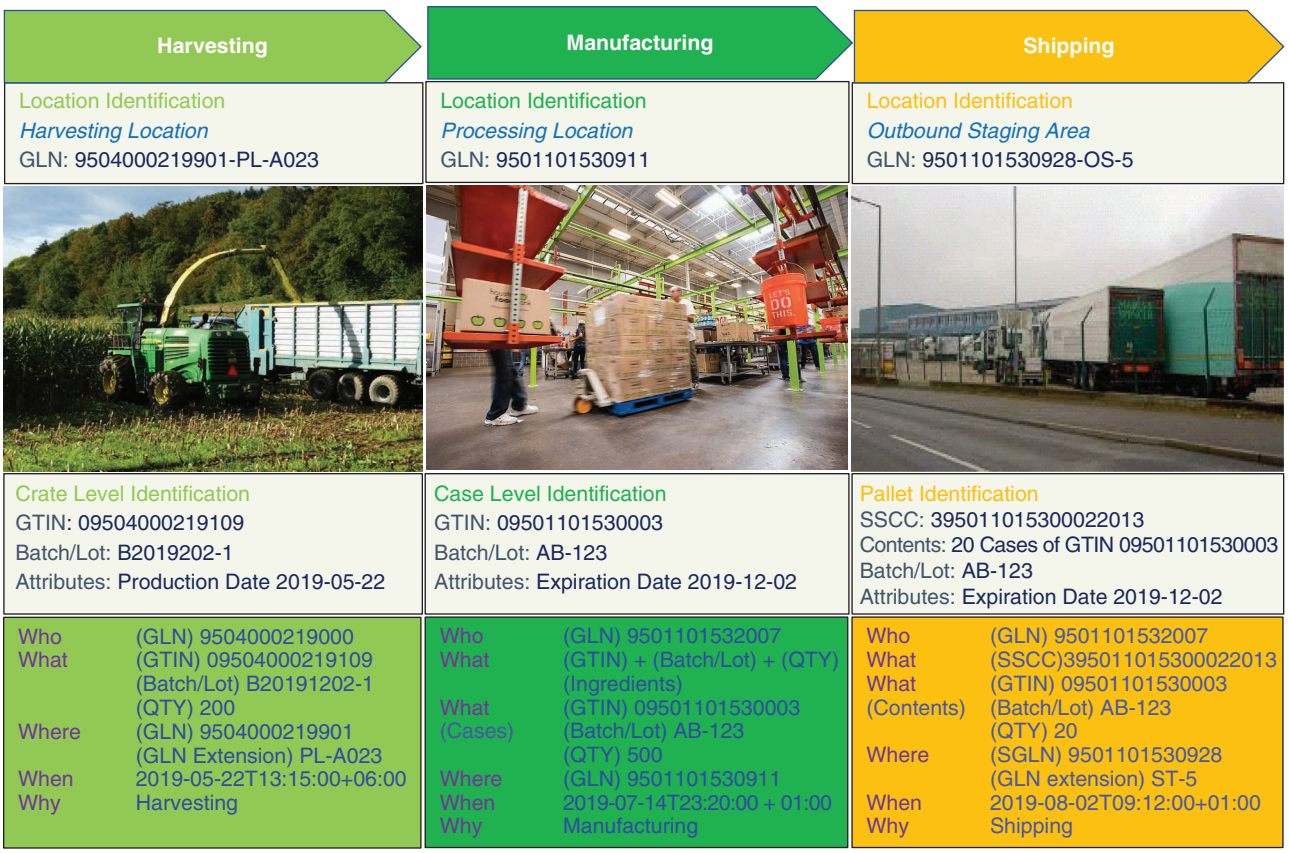

FIGURE 1. An illustration of GS1 standards in the food supply chain: (a) harvesting, (b) manufacturing, and (c) shipping.

adopted by the industry, and some retail chains like Whole Foods already mandate them.

Given a consistent implementation of GS1 standards, it is possible to achieve a rapid recall of problematic products. For example, South Korea has a "stop-sale" process; if a product is found to be unsafe, a GS1-centric message is sent to the retailers, and all of the points of sale can be blocked within 30 min. Similar national recall platforms are also present in United States, Canada, Australia, and New Zealand. However, with many parties involved, implementing such processes is cumbersome, and it is very difficult to ensure that the relevant information is not altered by a party for competitive advantages.[3]

HOW BLOCKCHAIN CAN HELP

In principle, the necessary operational data from the entire supply chain can be hosted in a cloud database and thus is available to all relevant parties to make intelligent decisions for improving both logistics operations and traceability. In practice, however, it is very difficult to ensure that all of the parties involved (for example, farmers, processors, logistics operators, retailers, warehouse operators, transport companies, food inspectors, and regulators) can trust the information contained in a central repository and that no party is able to alter it for its selfish gains.

> Transparency, traceability, and provenance are essential components of food logistics and becoming ever more important with advancing globalization and food technologies.

This is where the blockchain comes in. Blockchain is a cross-party distributed ledger technology that consists of a continuously expanding chain of records (or blocks), each corresponding to a sequence of transactions (or actions) that have been performed, with block size being a parameter of the mechanism. The blocks are time stamped and linked via cryptographic hashes; the transaction hashes within a block are arranged in the form of a Merkel tree to generate a single hash for the entire block, and each block contains the hash of the previous one. Each party maintains a private copy of the entire chain, and blocks can be entered in it following a consensus process. This makes the data entered in the blockchain immutable and tamper proof.

In an IoT-enabled food supply chain, the data coming out of the IoT devices can be used to create a record of the necessary information in the blockchain, which is illustrated in Figure 2. In the context of crops, the specific interactions between the logistics and the blockchain include the following:

- *at the farm*: storage of seed/crop details, for example, seed variety, type of growing such as organic, harvesting method, and crop storage information

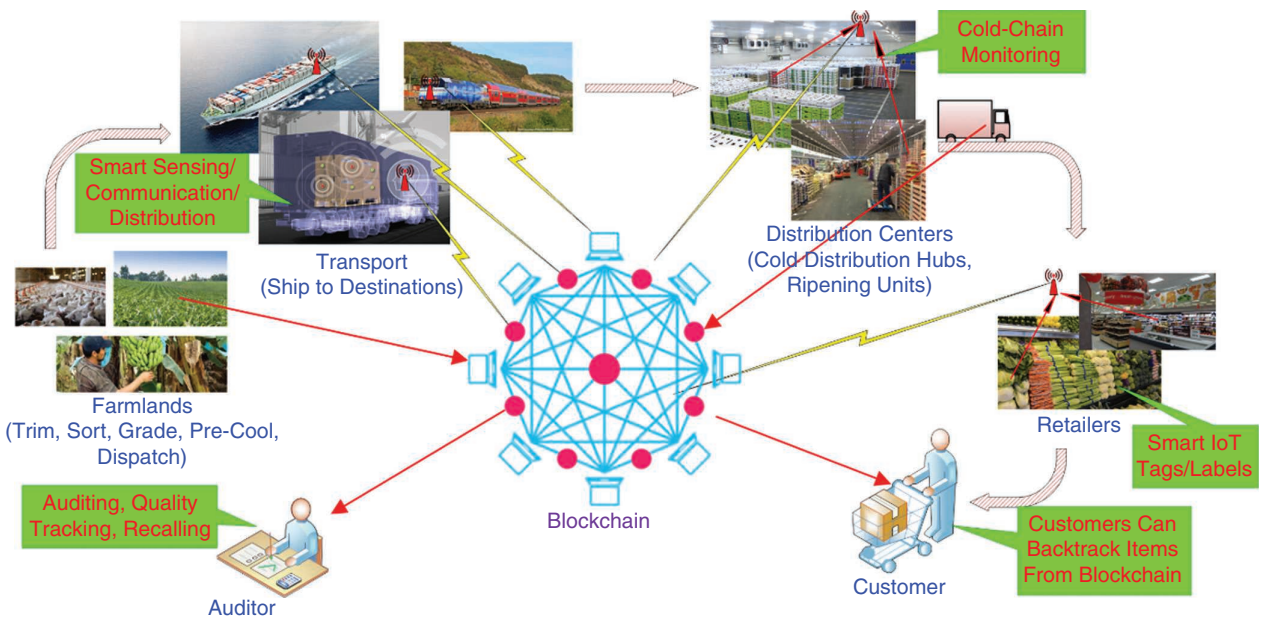

FIGURE 2. An illustration of information sharing and tracking in food logistics using blockchain.

- *at the processing facilities*: such as ingress condition of the crops, handling aspects (who handled what product and when), processing details, storage/refrigeration details
- *during transportation to wholesalers*: such as conditions (for example, temperature and quality) at the beginning, during transport, and in warehouses, damage during transport
- *during delivery to and dwelling at the retailer*: details of handling, product quality, and expiration dates of the retail packages (which are usually contained in bigger pallets used in the supply chain).

The information contained in the blockchain can be useful both to the end customers (for making informed decisions before buying the products) and the auditors (to ensure that the processing, handling, transportation, and storage regulations are being followed). It would also help the food transportation logistics since the recorded information can be used to make more intelligent decisions about proactive distribution of the food to minimize waste (for example, local distribution of food likely to spoil early) or avoiding transportation and distribution of food that may have quality issues.

In the case of food contamination in a large food chain, it can take weeks to months to identify the source of the origin. For example, in the case of the 2017 salmonella outbreak in Mexican papayas, it took two months to track down the source of the issue. In a complex, large multiparty supply chain, this leads to unnecessary recalls, loss of trust among the customers, spreading of food-borne illnesses, and even deaths. In a blockchain-enabled logistics system, such tracking time can be in seconds, which enables faster containment of food-borne illnesses, increased revenue due to faster response time and selective recalls, and increased trust among the partners. Walmart has already conducted two mock trials with IBM for tracking pork in China and mangoes in Mexico. These trials have demonstrated that using blockchain can reduce the time-to-track information from one week to 2.2 s.

Blockchain also reduces the possibility of human error or inaccuracies (either deliberate or accidental) caused by traditional paper-based records. Combining blockchain with automated IoT sensors, artificial intelligence, and industrial robotics will make it more robust and trustworthy. Several companies have started using IoT sensors to ensure food traceability. An example includes Shanghai-based ZhongAn Technology, which puts sensors on chickens to record their locations and how much they have moved on a daily basis. Similar initiatives have also been taken by Walimai on baby formula canisters, BeefLedger on Australian beef, and Chai Vault on investment-grade wines. Combining these industries with blockchain will transform the entire logistics sector and its associated processes.

The information contained in the blockchain can be useful both to the end customers (for making informed decisions before buying the products) and the auditors (to ensure that the processing, handling, transportation, and storage regulations are being followed).

CURRENT EFFORTS OF BLOCKCHAIN IN FOOD LOGISTICS

Many of the world's largest food suppliers are collaborating on blockchain solutions for inventory and quality management and tracking the source of foodborne illnesses. For example, many large food suppliers and retailers, like Dole, Unilever, and Walmart, are partnering with IBM in its FoodTrust initiative. Blockchain in Transport Alliance is a consortium consisting of nearly 500 members in more than 25 countries, ensuring better freight tracking and efficiency in logistics. OriginTrail is a Slovenia-based company that has taken the traceability initiatives and created a consortium called Trace Alliance. OriginTrail saves fingerprints of data on the blockchain to reduce the cost to only cents per item or even a fraction of a cent if done at the batch level. London-based Provenance and Chinese giant Alibaba are also using blockchain to improve their customer confidence. In addition, Beijing-based JD.com has started working with its exporters in Mongolia and Australia to track the breeding, raising, processing, and transporting of beef using blockchain.

The adoption of blockchain among the food logistics players is still in its infancy, although there is recent literature on the subject.[4,5] One of the major challenges is to develop common standards that will make the technology universally applicable across different supply chains. To get the maximum value out of blockchain, the technology needs to be adopted by all players across the logistics industry, and the costs of participation for small players should not be prohibitive.[3] Another important requirement is in dealing with real-world issues that involve human errors, participants going out of business, constant changes in business relationships and policies, changes in regulations, and so forth. Although specific technical solutions can be devised to handle these situations, a broad set of

standards and consensus from multiple players (for example, government regulators/inspectors, distributors, farmers, and retailers) is essential to achieve a broadly acceptable and workable solution. Also, given multiple players with different data privacy policies and parties with a variety of roles (for example, regulators, inspectors, shippers, and sellers), "permissioned" blockchains are essential. It is possible to provide this access control through a blockchain itself that stores smart contracts;[6,7] however, the speed and ability to alter policies need to be examined.

A fundamental issue in using blockchains for a complex application is what information should be on the blockchain directly and what should be stored elsewhere and accessed through the blockchain. The former implies significant storage overhead (due to replication) and difficulty in updates (due to immutability) but assures the integrity of the information, whereas the latter implies the opposite. Another issue concerns the consensus mechanism; the stakeholders may want agreement across all parties, but this does not provide any tolerance against network disconnections or long delays.

LOOKING AHEAD

The blockchain technology provides some unique advantages for managing the food supply chain due to the involvement of numerous parties spread worldwide. However, the technology also has limitations in terms of its heavy-duty computing infrastructure requirements and inadequate transactional rates to meet the needs of a global supply chain.

Several approaches are being pursued to improve the transaction speed of blockchains. One technique is sharding, which essentially splits up the entire network into smaller subchains, with each having its own state and transaction history. Another idea used by Raiden Network and Plasma is to build multiple child chains apart from the main chain to process some of the transactions separately and periodically settle their states with the main chain. Running multiple parallel chains can also improve the throughput and transaction speed. In addition to the throughput, indeterminate latency over the Internet and poor connectivity in certain areas can lead to unacceptably long transaction times.

> Many of the world's largest food suppliers are collaborating on blockchain solutions for inventory and quality management and tracking the source of foodborne illnesses.

To ensure the widespread use of blockchain in food logistics, it is critical to introduce open standards for food logistics related to data collection, representation, storage, and access control. It is also crucial to have standardized mechanisms to handle various real-world situations and to mitigate any adverse effects for consumers and the general population.

REFERENCES

1. A. Pal and K. Kant, "IoT-based sensing and communications infrastructure for the fresh food supply chain," *Computer* vol. 51, no. 2, pp. 76–80, Feb. 2018.
2. D. Gunders, "Wasted: How America is losing up to 40 percent of its food from farm to fork to landfill (TR-2012)." Accessed on: Jan. 28, 2019. [Online]. Available: https://www.nrdc.org/sites/default/files/wasted-food-IP.pdf
3. S. Pearsona et al., "Are distributed ledger technologies the panacea for food traceability?" *Global Food Security*, vol. 20, pp. 145–149, Mar. 2019.
4. Z. Li, H. Wu, B. King, Z. Ben Miled, J. Wassick, and J. Tazelaar, "A hybrid blockchain ledger for supply chain visibility," in *Proc. 2018 17th Int. Symp. Parallel and Distributed Computing (ISPDC)*, Geneva, pp. 118–125.
5. C. Narayanaswami, R. Nooyi, S. R. Govindaswamy, and R. Viswanathan, "Blockchain anchored supply chain automation," *IBM J. Res. Develop.*, vol. 63, no. 2/3, pp. 7:1–7:11, Mar.–May 2019.
6. S. Wang, D. Li, Y. Zhang, and J. Chen, "Smart contract-based product traceability system in the supply chain scenario," *IEEE Access*, vol. 7, pp. 115,122–115,133, Aug. 2019.
7. Y. Zhang, S. Kasahara, Y. Shen, X. Jiang, and J. Wan, "Smart contract-based access control for the internet of things," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 1594–1605, 2018.
8. J. G. Keogh, "Blockchain, provenance, traceability & chain of custody." Accessed on: Sept. 12, 2019. [Online]. Available: http://www.myfoodtrust.com/2018/08/17/blockchain-provenance-traceability-chain-of-custody/

AMITANGSHU PAL is with the Computer and Information Systems Department at Temple University. Contact him at amitangshu.pal@temple.edu.

KRISHNA KANT is with the Computer and Information Systems Department at Temple University. He is a Fellow of the IEEE. Contact him at kkant@temple.edu.