Distributed Ledger Technology

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"Distributed Ledger Technology (DLT) is a term used to represent a digital network of distributed models, consisting of blockchain-based ledgers, and collaborating on shared tasks and activities. Blockchain technology is a data structure, composed of “blocks”, that are cryptographically linked together in a chained sequence using cryptographic hashes, secured against manipulations. Due to wider functionality, DLT is a commonly used term for a computer-based system consisting of distributed ledger-based data structures, which can provide increased levels of trust, service availability, resiliency, and security of digital systems, as well as distributed storage, computation, and control."

Keywords: distributed ledger technology ; Internet of Things ; food supply chain ; blockchain ; sustainability ; IoT

1. Distributed Ledger Technologies - Brief Description and Definition

Distributed Ledger Technology (DLT) is a term used to represent a digital network of distributed models, consisting of blockchain-based ledgers, and collaborating on shared tasks and activities. Blockchain technology is a data structure, composed of “blocks”, that are cryptographically linked together in a chained sequence using cryptographic hashes, secured against manipulations [1][2]. Due to wider functionality, DLT is a commonly used term for a computer-based system consisting of distributed ledger-based data structures, which can provide increased levels of trust, service availability, resiliency, and security of digital systems, as well as distributed storage, computation, and control [2].

Integration of blockchain technology in Internet of Things (IoT) systems can potentially improve system and cyber security, safety [3][4][5], data confidentiality [6] and data integrity [4]. For instance, blockchains can help prevent food fraud by retaining trustworthy product information on biological and geographic origin [3][7]. The combination of blockchains with IoT can potentially improve FSCs transparency, efficiency, and sustainability [4][8] save costs and time [7][5][4], reduce information asymmetry, paperwork, fraud risks, and increase trust among supply chain stakeholders and end consumers [4][8]. Integration of DLTs across organizations and infrastructures can potentially enhance stability, resilience, and security of systems [2][5], enabling distributed solutions for industries and societies.

2. Scalability Challenges

The most frequent and prominent challenge, which was identified in the selected literature, was the scalability issue of blockchain and IoT implementation in FSCs, i.e., the ability to maintain transactions of a network at scale without business process interruption [9]. The consensus algorithms of blockchains, such as Proof-of-Work and Proof-of-Stake, require competition for computational resources, hence achieving scalability and stability in blockchain and IoT-based systems is still a challenge [10].

Current existing blockchain platforms, such as Hyperledger Sawtooth, are not capable to handle high amount of data arriving simultaneously, including sensory data and IoT data, due to the low maturity of the solution. [11] highlighted the scalability issue of Hyperledger Sawtooth and suggested to dedicate research efforts towards improvement of blockchain scalability [11]. Another solution of the Hyperledger Fabric Composer was investigated by [12], who implemented an experimental study with RFID and IoT for traceability of a halal FSC.

Another blockchain platform, Ethereum, was compared with Hyperledger Sawtooth with respect to performance by [13]. They presented a fully decentralized IoT-integrated blockchain-based traceability solution for agri-food supply chains. From a performance perspective, the Hyperledger Sawtooth performed better than Ethereum with respect to CPU load, latency, and network traffic. Ethereum had better scalability performance and reliability with increased number of participants, as well as better software maturity [13].

Another way to address the scalability issue of blockchains was the implementation of various mechanisms, one of which being the “sharding” mechanism integrated by [14]. They introduced a permissioned 3-tier blockchain framework, with integrated Hazard Control and Critical Control Point (HACCP), permissioned blockchain, and IoT infrastructure. The “sharding” mechanism used a set of parallel blockchains, called “shards”, to scale the network with large number of transactions in multiple shards in parallel. The task of verifying transactions was divided across multiple shards, and each shard maintained its own synchronized ledger, allocating the shards according to geographic zones. The network performance was evaluated in a simulation, and resulted in a query time of just a few milliseconds even when the data was gathered from multiple shards [9][14] also mentioned the “sharding” mechanism to improve scalability by dividing blockchain data into several nodes or shards, thereby spreading computational power among the nodes simultaneously. In their review, private and consortium blockchain solutions were considered more scalable comparing to public ones, since in public blockchains all nodes share identical responsibilities, e.g., an establishment of a consensus, interaction with user and ledger management [9]. Consortium blockchains are shared among a consortium of multiple institutions, which have access to the blockchain [15]. Private blockchains, on the other hand, allocate tasks to different nodes, which improves performance of the network. Public Ethereum blockchain is able to support 15 transactions per second, while private blockchains, such as Hyperledger Fabric, can provide 3500 transactions per second [9]. Efficient “lightweight” strategies of consensus mechanisms were suggested to address the issues of scalability, data integrity and privacy by performing any expensive high-computational tasks off-chain [9].

Various decentralized storage solutions were investigated to improve the scalability of blockchain solutions. The *Interplanetary File System (IPFS)* and Ethereum blockchain were integrated for decentralized storage of IoT data in an automated FSC traceability model [16], in agri-food prototypical [17], and system design solutions [18][19]. Manufacturer data and various quality inspections details were stored in a centralized server, while IoT data was stored in a so-called table of content (TOC) located both on a central server and on a decentralized database of IPFS. This method allowed a faster transaction process and backward traceability, tracking each product by the TOC identifier from each supply chain member [16]. In addition to the IPFS, different hybrid storage solutions were proposed, including lightweight data structures and a Delegate Proof-of-Stake consensus mechanism, which restricts the number of validators to improve the scalability of the blockchain [20]. Hybrid on-chain and off-chain data storage solutions were described [21][22], such as DoubleChain [20], as well as smart contract filtering algorithms, such as a Distributed Time-based Consensus algorithm, to reduce on-chain data [20]. Additionally, grouping nodes into clusters in the Blockchain of Things infrastructure was suggested to improve blockchain scalability [20].

In [23], a decentralized storage solution for blockchain in the FSC domain was also integrated to enhance throughput, latency, and capacity, introducing the BigchainDB. The real-time IoT sensor data and HACCP were integrated for real-time food tracing. Throughput and latency issues were addressed with the BigchainDB for distributed database, which could increase throughput and data storage in a positive linear correlation, while maintaining blockchain properties, such as immutability, transparency, peer-to-peer network, chronological order of transactions, and decentralized user governance with a consensus mechanism [23].

Moreover, [24] proposed using a lightning network technology with edge computing in a blockhain-based food safety management system to improve transaction and performance efficiency. Real-time transactions were carried out in an off-chain channel without uploading data on to the blockchain. A dynamic programming algorithm was applied to reduce lightning network fees [24].

Another approach was the introduction of a new consensus algorithm, proposed by [10], who addressed the issue of blockchain scalability by integrating IoT, IBM cloud and blockchain in a scalable traceability system. A system prototype was presented with an integrated consensus mechanism, called the proof of supply chain share, as well as fuzzy logic to perform shelf-life management for perishable food traceability. The feasibility of the proposed model was evaluated with a case study in a retail e-commerce sector [10]. A two-level blockchain solution was additionally proposed by [25], who performed a case study-based pilot project, combining a permissionless (public) ledger, shared externally, with a permissioned ledger, available only to licensed stakeholders [25].

The major concern of recent blockchain developments is the technological immaturity [21], and many approaches highlighted the lack of solid scalable blockchain solutions. Most blockchain initiatives stay in a small implementation or proof-of-concept phase through small pilot studies, while large scale implementations and integration to normal operations are usually initiated by companies, and are not widely represented in research publications [26]. Blockchain technology is still perceived by organizations as an emerging technology and an “experimental tool” for achieving a potential competitive advantage in future [26].

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