Performance Evaluation of Blockchains Towards Sharing of Digital Twins

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***Abstract*—Citizens need to be involved to construct digital twins by sensing the urban environments using their IoT devices and sharing the sensed data among application providers. This "cooperative sensing" is one of the key solutions to achieve sustainable smart cities/super cities and offers improvement of the Quality of Life of citizens. In this view, blockchain and distributed ledger technology are collecting much attention to build a distributed data exchanging/sharing system for IoT data as well as cryptocurrency. However, the blockchain has a scalability issue in terms of large data volume and high-frequency transaction cases. In this paper, in order to reveal the comprehensive performance of blockchain when it is applied to sensor data sharing, we build a data-sharing system using Hyperledger Fabric which is one of the well-known blockchain platforms and evaluate the system performance by using a variety of sensing data, including images and 3D objects.**

Keywords—Blockchain, Hyperledger Fabric, Data sharing system, Digital Twins

I. Introduction

Digital twin helps to create services to improve Quality of Life (QoL). It requires various state-of-the-art information and communication technologies (ICTs), including Internet of Things (IoT), 5G/Beyond 5G, trust and security, life science and technologies. In particular, in order to achieve early realization of digital twins and to build sustainable smart cities/super cities, it is mandatory to decouple data providers from application providers, and for every citizen to play the important role of the data provider. In this view, recently, blockchain and distributed ledger technology are collecting much attention to build a "trust-free" distributed data exchanging/sharing system for smart cities [1]. Blockchain offers a decentralized data management system and ensures immutability and consistency.

However, the blockchain has a scalability issue on handling of large data volume and high-frequency transaction cases. Many researches have reported the performance analysis of the well-known blockchain systems, such as Hyperledger Fabric [2]. For instance, [3] conducted the performance analysis of Hyperledger Fabric v0.6 and v1.0 and concluded that Hyperledger Fabric v1.0 did not provide the acceptable performance under high workload scenarios. Similarly, [4] evaluated the throughput and latency characteristics of Hyperledger Fabric v1.0 under different workload sets. In addition, [5] proposed CATP-Fabric for delay-sensitive IoT applications.

Inspired by those research efforts, in this paper, we build a blockchain-based data sharing system using Hyperledger Fabric v2.2.2 (newer version from the previous works) and evaluate the system performance by using a variety of sensing data, including images and 3D objects (3D point cloud data).

II. Blockchain-based Data Sharing System

Figure 1 shows an conceptual image that describes how we adopt blockchain system as a data sharing system. As mentioned in the previous section, we aim at decoupling the data providers from application providers. The data sharing system bridges between two providers and offers data free flow with trust across different smart city/super city organizations. Because we assume that each blockchain node is managed by each organization, we choose Hyperledger Fabric as a blockchain system. Hyperledger Fabric is a well-known "permissioned" blockchain system and has a better system performance (e.g., response time and throughput) compared to the "permissionless" blockchain system because of a light-weight consensus process.

Hyperledger Fabric (blockchain node in Fig.1) is mainly composed of four function blocks: certificate authority (CA), chaincode, orderer and peer. Here, we briefly summarize their functions by referring to the official document of Hyperledger Fabric [6]. A CA mainly has capabilities of registration of users' identities and issuance of Enrollment Certificates. A chaincode, also known as a smart contract, is a heart of a Hyperledger Fabric and defines the transaction logic. In addition, every smart contract has an endorsement policy to validate transactions. An orderer offers to determine an order of the transactions, create a block from the transactions, and distribute the block to peers. A peer hosts a ledger which consists of two kinds of data: world state and blockchain. World state represents the current values of a set of ledger states, and blockchain represents a record of all transaction logs. In addition, the peer instantiates the chaincode. It should be noted that a transaction flow is consists of endorsement, ordering and validation.

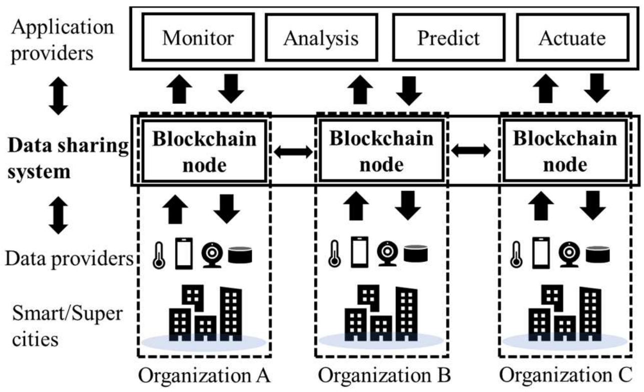

Figure 1. Overview of blockchain-based data sharing system

In order to share/exchange data using Hyperledger Fabric, we implement a simple smart contract (read/write data) and install as a chaincode. By calling the smart contract, a user can make a transaction. When the transaction is validated, the user

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can write a sensing data to the ledger and read a sensing data from the world state. Every sensing data is stored to the blockchain as a transaction log.

III. Performance Evaluations

In this section, we demonstrate the system performance of the blockchain-based data sharing system. In the experiment, we used Hyperledger Fabric v2.2.2 and Hyperledger Caliper, to measure a response time and throughput for transactions. We used three mini PCs (Intel NUC): two for blockchain nodes (we emulated two organizations A and B) and one for Hyperledger Caliper and a client application. The blockchain peer and orderer are run on Docker containers. We do not prepare CA in this case because we assume that the user authentication is done in advance. We hard-coded certificates and private keys in the transaction.

The objective of the evaluations is to validate the system performance when we exchange sensing data related to digital twins. Thus, we used two PNG images (250KB and 419KB) and two 3D point clouds (1.3MB and 3.7MB) as sensing data. 3D point clouds are captured using RealSense L515 in our laboratory (a whole room scene and a chair).

We employ two different scenarios: upload (write) the data and download (read) the data. For the upload case, we observe the response times for a single transaction, including each transaction phase: endorsement, ordering and validation. The user sends the transaction to the Peer A, and the number of trails is five. For the download case, we evaluate average response times and maximum throughputs of transactions under different request data sizes and transaction rates.

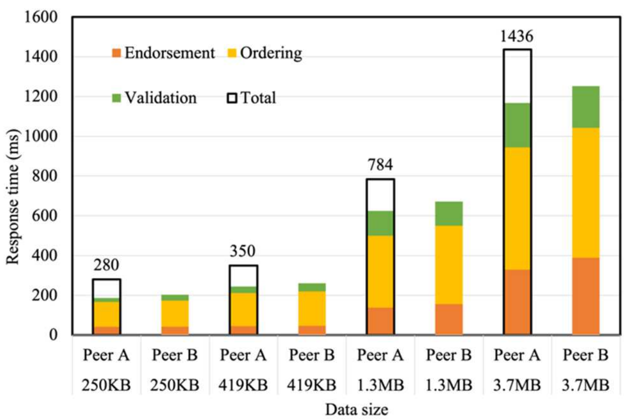

Figure 2. Average response time for uploading data

Figure 2 shows the results of average response times of the upload case. As shown in the figure, the response time of the ordering phase increases drastically because the transmission delay increases. We can, however, conclude from the result that approximately 450KB data can be handled with an acceptable response time.

Table I summarizes the results of average response times and maximum throughputs of transactions. Unsurprisingly, as differed from the upload case, the scalability issue is mitigated in the download case. This is because, in this case, the user can retrieve data from the ledger (world state) without ordering and validation phases.

Table I: System performance for download data

Data size	Average response time (sec)	Throughput (tps)
250 KB	0.12	147.68
419 KB	0.1	99.16
1.7 MB	0.17	36.56
3.7MB	0.49	12.88

IV. Conclusions

In this paper, we introduced the blockchain-based data sharing system and implemented it using Hyperledger Fabric v2.2.2. For the performance validation, we evaluated the response times and throughputs of transactions when the PNG images and 3D point clouds are uploaded/downloaded to the system. From the experiment, we concluded that Hyperledger Fabric could be adopted as a data sharing model when the system handles still images (e.g., the data has a moderate size). In the future, we will evaluate the system performance in the larger scale environments and consider other light-weight blockchain systems.

Acknowledgment

This paper is supported by the EU-JAPAN initiative by the EC Horizon 2020 Work Programme (2018-2020) Grant Agreement No. 814918 and Ministry of Internal Affairs and Communications “Federating IoT and cloud infrastructures to provide scalable and interoperable Smart Cities applications, by introducing novel IoT virtualization technologies (Fed4IoT) (JPJ000595)”

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