2020 IEEE 22nd International Conference on High Performance Computing and Communications; IEEE 18th International Conference on Smart City; IEEE 6th International Conference on Data Science and Systems (HPCC/SmartCity/DSS)

2020 IEEE 22nd International Conference on High Performance Computing and Communications | 978-1-7281-7649-9/20/$31.00 ©2020 IEEE | DOI: 10.1109/HPCC-SmartCity-DSS50907.2020.00154

Distributed-to-Centralized Data Management through Blockchain Technologies in Large-Scale IoT Networks of Multicampus University

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***Abstract*— Traditionally, blockchain technologies focus on data security and privacy issues in different business domains of smart cities. However, we believe that blockchain technologies can be beneficial for data and resource management in large-scale internet of things (IoT) networks of smart cities. Blockchain technologies and their related consensus algorithms and miners may apply through multilevel information communication technology (ICT) architecture in large-scale IoT networks of smart cities to organize the city-data and ICT resources. This position paper addresses an initial idea about the contribution of different smart cities and ICT concepts, including "blockchain technologies," "distributed-to-centralized ICT architecture (D2C-ICT)," "distributed-to-centralized data management (D2C-DM)," and "smart university." We first present our D2C-ICT architecture in the smart university context using different distributed and centralized technologies, including cloudlet and cloud technologies. Finally, we show that the facilities of blockchain technologies for data and resource management through D2C-ICT architecture in large-scale IoT networks of smart cities.**

Keywords*— *Smart City; Smart University; large-scale IoT networks; blockchain technologies; distributed-to-centralized ICT architecture (D2C-ICT); distributed-to-centralized data management (D2C-DM)

I. Introduction and Motivation

A smart city includes different business domains in a city, including smart transportation, smart hospital, smart home, etc. [1-4]. University is one of the active business domains in a city. A modern university, which can also be named a smart university, is a modern ICT management system in the university to collaborate and build a modern and interactive university system. That could be possible by interacting with students, lecturers, administration staff, IoT data sources, and other physical and non-physical data sources in a university.

The smart university is a complex scenario concerning managing and organizing their resources and assets for their university stakeholders, including students, teachers, staff, visitors, etc. [2, 5]. Many IoT data sources can exist from smartphones to sensors, video conferences, and so on by thousands of university stakeholders in the university scenario. Therefore, the smart university goes beyond different ICT management strategies (including data management [6-8] and resource management [6, 9]) to make extra facilities for their university stakeholders, including the connection between all other campuses in case of multi-campus university and also interaction with another local and worldwide universities [2, 10]. All ICT management strategies help smart-university stakeholders organize their knowledge and information sharing and eliminate other resource waste.

Traditional ICT management strategies (including resource and data management architectures) in smart cities has been oriented by centralized facilities based on cloud computing technologies [6, 11]. Several benefits can be gained by using cloud computing technologies, including (almost) unlimited resources capacity, the cost benefits regarding the market scale, the elasticity schema (pay as you go model), and so on [12, 13]. Besides, there are several disadvantages through forwarding all data and services to cloud technologies, including data quality and security issues, high communication latencies, network overloading, etc. [14-17]. Therefore, centralized ICT management strategies may extend with decentralized and distributed technologies as an emerging technology to contribute between the edge of networks (as a place which is the nearest place to the data sources) and centralized schema (as a place which is the furthest place to the data sources) [4, 8, 18, 19]. These unified strategies are based on designing distributed-to-centralized and decentralized-to-centralized ICT architectures [56-62]. For instance, fog computing contributes to the edge of networks (close to the data sources) to enhance the cloud technologies' performance at the edge of the network [17, 20]. Several benefits can be achieved by distributed-to-centralized ICT management strategies and architectures (including communication latency, the network load, etc. [14-18, 20]).

Blockchain is a recently emerging technology [21-23]. Nowadays, blockchain technology has been proposed as an open, distributed, decentralized schema for ICT management strategies [21, 22]. Moreover, blockchain technology goes beyond different scenarios, sciences, and business models (from financial trades [22] to smart cities [3, 23] and many other scenarios [24-28]) to handle the ICT management strategies and requirements in large-scale IoT networks in smart cities, including resource management [29-33] and data management [34-36]). Indeed, several advantages can be achieved the blockchain technology, such as self-sovereignty, trust, transparency and provenance, immutability, disintermediation, collaboration, data management costs, etc. [26, 28].

The rest of the paper is structured as follows. Section II introduces the core background related to different technological management strategies (such as resource management and data management) in the context of a smart city. Moreover, this section presents the blockchain technologies in different smart cities' business domains. Section III discusses the main insights related to data management and two main D2C-DM architecture, including fog-to-cloud data management (F2C-DM) and cloudlet-to-cloud data management architecture (c2C-DM). Section IV discusses blockchain technologies concepts. Section V describes an architectural model to present the contribution of ICT and its data management architecture to blockchain technologies and smart university ideas. Finally, Section VI concludes the paper and addresses the possible future work of this position paper.

II. Related Work

Multiple ICT architectures in smart cities are designed for large-scale IoT networks management of smart cities [6, 11, 17, 20], including centralized, decentralized-to-centralized, and distributed-to-centralized.

Centralized ICT architecture used cloud computing technologies that all physical ICT resources must be in one centralized place [6, 11]. Decentralized and distributed ICT architectures [56-60] are the next possible solution by using is different technologies, e.g., fog [17, 20] or cloudlet [37]. Those technologies use the potential of the physical devices and resources where data is produced in a city [17, 20]. Moreover, several proposals combine the resources of the centralized and distributed technologies for further processing and storage, for instance, fog-to-cloud [4, 7, 8] or fog-to-cloudlet-to-cloud [9, 55, 56].

Data management is one of the main parts of ICT architecture. Data management follows the same ICT architecture idea of centralized, decentralized-to-centralized, and distributed-to-centralized. So, three main proposals are available for the data management architecture in smart cities, centralized data management (CDM-DM), decentralized-to-centralized (DC2C-DM), and D2C-DM, as explained in [6, 11].

The CDM-DM architectures highlighted that data management schemes are designed through centralized ICT architecture and put all city-data in one place. This idea highlights that the data is produced from many various data sources spread across the city, but data can be stored and reached from a centralized platform, mainly using cloud-computing technologies [6, 11]. The DC2C-DM and D2C-DM architectures [4, 8, 18, 19] suggested using various distributed technologies for data management, such as Fog [9, 17, 20] or cloudlet technologies [37]. DC2C-DM and D2C-DM architecture have used both potentials of cloud and distributed technologies simultaneously for handling data management requirements in a city [4, 8, 18, 19].

Blockchain technology is highly popular for non-centralized data and application concepts in academia and industries nowadays [21-23]. On the one hand, the blockchain proposal is used in many different scenarios and environments. For instance, finance and trade organizations [22], food supply chain industry [21], education and learning environments [24-28] (such as digital student certification issues and other related certificate topics), and smart cities (including smart contract [24], smart home [3, 23], and other related topics [33, 35, 36, 38, 39]). On the other hand, several different ICT management strategies proposed blockchain technology, including data management and resource management [20, 21, 29-33, 42]. The data management focuses on data security [3, 21, 23, 24, 26, 34, 35, 40] and data storage management [23, 28, 33, 36, 38, 41].

To sum up, with the focus on smart university scenarios, almost all blockchain models suggested for digital certification issues (including issuing, validating, and sharing educational certificates) are concentrated on data security and privacy concepts. Also, there is no previous work for ICT and its data management architecture proposal (explicit on the D2C-DM architecture) tailored to the concepts of the “smart university” [43-45].

III. D2C Data Management in Smart City Scenario

Almost all non-centralized ICT architectures in smart cities are designed by using fog computing technologies. Therefore, almost all data management architectures related to these ICT architectures are designed based on DC2C-DM architecture [4, 8, 18, 19].

This section is organized into two main subsections. First, we briefly explain the fog-to-cloud data management architectures (F2C-DM) in the smart city as an example of DC2C-DM. Second, we propose our idea of D2C-DM by using cloudlet and cloud technologies.

A. *F2C-DM architecture*

Fog computing technologies have been emerged by Cisco [37]. Fog computing can contribute to devices on the edge of networks to make resources and data management facilities on the IoT networks [17, 20, 46, 47]. By using Fog technologies, data may not be forwarded to a central place, usually in the cloud technologies [4, 8, 18, 19]. Therefore, network traffic and latencies can be reduced and optimized. Moreover, F2C-DM architecture offered a hierarchical architectural design [4, 8, 18, 19]. This architecture allocated cloud computing for deep storage and processing on the one hand. On the other hand, fog computing is used to extend cloud computing at the network's edge. It then makes the possibility for the architecture to access real-time data for the critical applications and processing related requirements [4, 8, 18, 19]. Also, in [4, 8, 18, 19], the F2C-DM architectures are assumed by a variable number of layers from fog to cloud technologies concerning the business and data model requirements.

B. *c2C-DM architecture*

Cloudlet technologies have been offered by CMU [37]. Fog and cloudlet technologies follow almost the same principles.

However, the main difference is the capacity of resources in fog and cloudlet. Fog technologies are using the potential of the smart cities' data sources, such as switches, routers, etc. However, the cloudlet technologies prepare a "data center in a box" at the network's edge. Therefore, this idea brings cloud services closer to users and data sources [37].

The main difference between F2C-DM and c2C-DM is the interconnection between city data sources. In F2C-DM architecture, edge and IoT devices can communicate with each other through accessing cloud technologies. However, in c2C-DM architecture, the edge and IoT devices can communicate through cloudlet technologies available in a city and close to the city-data sources.

IV. Blockchain Technoliges

The initial concepts of blockchain technology were discussed in 2008 [27]. Blockchain technology went beyond different environments and scenarios, from digital finance and trade (bitcoin) to different smart city scenarios and other sciences and big data environments [27]. On top of that, blockchain technologies started to deal with the idea of the decentralized data management framework [30]. However, on one side, most of the decentralized data management framework idea has been focused on data security issues [3, 21, 23, 24, 26, 34, 35, 40] and data storage management concepts [23, 28, 33, 36, 38, 41] on one side. On the other side, there are only a few proposals for distributed-to-centralized schema through blockchain technologies [30, 34-37].

Blockchain technologies are based on a distributed ledger schema. The distributed ledger can consider as a distributed database of records (including a public ledger of digital issues or transactions) [28, 30]. Data sources then produce data, and then the data is then recorded through blockchain as blocks. Therefore, blockchain technology's base is performed as a linked list data structure to define logical relations among data extended to the blockchain. This way highlights that no centralized entity or intermediary is requested to support data blocks [30].

The current blockchain architecture is composed of blockchain, and Consensus and Miners [3, 24, 41] as shown details below:

- The blockchain: constitutes from different blocks. Each block has a particular structure (including header and block contents). The header of the block consists of Merkle root, hash address (including previous and current block), timestamp, and other additional information (such as the signature of the block, nonce value, or other description information) [28, 39]. In addition, the first block is namely called a genesis block [30].
- Consensus and Miners: The main purpose of the consensus algorithms is the election of a leader. Then the leaders can validate a new block and then publish the block through their related network. In addition, miners usually are attaching the generated blocks to the chain. If the mining process has discarded any node, it means the node does not follow the basic needed requirements to attach to the chain [39].

V. Proposed Data Management Architecture For Real Use Case: Smart University

NTNU is located in the large peninsula shared with Sweden in the north of Europe. NTNU University is the largest university in Norway since 1760 [48]. Also, NTNU University has focused on engineering, technology, and natural sciences, but the university has students, instructors, and researchers across social sciences, health sciences, medicine, arts, humanities, etc. There are three different main campuses in the cities of Trondheim (including Gløshaugen, Dragvoll, Tyholt, Øya, Kalvskinnet, Midtbyen, and Nedre Elvehavn campuses), Gjøvik, and Ålesund in Norway [49]. For more information, each NTNU branch covers with numbers of the different department as shown in detail below:

- Trondheim branch constitutes nine departments (Humanities, Architecture and Design, Information Technology and Electrical Engineering, Engineering, Medicine and Health Sciences, Natural Sciences, Social and Educational Sciences, Economics and Management, and Museum) [50].
- Gjøvik branch has eight distinct departments (consisting of Health Science, Information Security and Communication Technology, Manufacturing and Civil Engineering, Electronic Systems, Computer Science, Industrial Economics and Technology Management, Mathematical Sciences, and Design) [51].
- Ålesund branch includes five different departments (International Business, ICT and Natural Sciences, Ocean Operation and Civil Engineering, Biological Sciences, and Health Sciences) [52].

This section is categorized into two main subsections. First, we explain our proposed c2C-DM architecture and their related data blocks (data acquisition, data processing, and data preservation) for the smart university. Then, we integrated the c2C-DM architecture into the blockchain technology for the smart cities' scenario. We briefly explain the different layers of blockchain technology through the c2C-DM architecture in smart university.

A. c2C-DM architecture for NTNU University, Norway

The c2C-DM architecture is depicted in Fig.1 through D2C-ICT architecture and has two layers, cloudlet- and Cloud-layer, as described below:

- **cloudlet Layer:** this layer is the nearest layer to the city's end-users and data sources. This layer is managed by the same city's cloudlet technologies as data end-users and data sources are. This layer can cover all data management requirements in a city dependent on cloudlet resources' capacity as virtual or physical servers. If the capacity of resources is not sufficient, we can use the facilities of cloud technologies somewhere out of the city.
- **Cloud Layer:** Cloud covers the almost unlimited resources in terms of processing and storage. The cloud layer is also positioned in a place that can be very far away from the city, for instance, in a different city or country or continent. Therefore, network communication between the city and the

cloud layer is essential in this scenario, including network latencies and other related parameters.

The proposed D2C-ICT architecture and its c2C-DM architecture used both the potential of distributed and centralized technologies simultaneously.

B. Blockchain technologies through c2C-DM architecture for NTNU University, Norway (multicampus university)

Fig.2 illustrated a C2C data management architecture based on blockchain technologies for smart university scenarios. The proposed architecture prepares the facility to develop the large-scale University's distributed network for the university stakeholders (including students, teachers, etc.) in a high-efficiency and effective way. Blockchain technology has been designed in three layers in the architecture, including ordinary nodes, miner nodes, and blockchain nodes, as shown below.

- **Ordinary node:** The ordinary node is formed by each data source at each campus/branch department. The ordinary node aims to generate data for our scenarios (data generation). The generated data (by ordinary node) will send to the upper layer through a particular user interface.
- **Miner node:** Cloudlet technologies apply the miner node on top of each University's branch in our scenario. The miner node has three main tasks, as shown below:
  - firstly, each miner node will collect all produced data by the under-layer ordinary nodes first (data collection);
  - Secondly, all collected data can be filtered and aggregated through specific policies and algorithms by the miner node (data filtering and aggregation);
  - Thirdly, each miner node has a facility to connect to their nearest neighbors to update their related data collection information and description (data description), such as their hash tables;
  - Finally, the miner node will propose the collected data (after applying data filtering, aggregation, etc.) to create a block under the blockchain strategies at the cloud layer.
- **Blockchain node:** The Cloud layer covers all the blockchain nodes. The blockchain node can provide appropriate blocks for the collected data under particular data and block structures (such as timestamp, expiry date, Merkle root, etc. [3, 36, 39]).

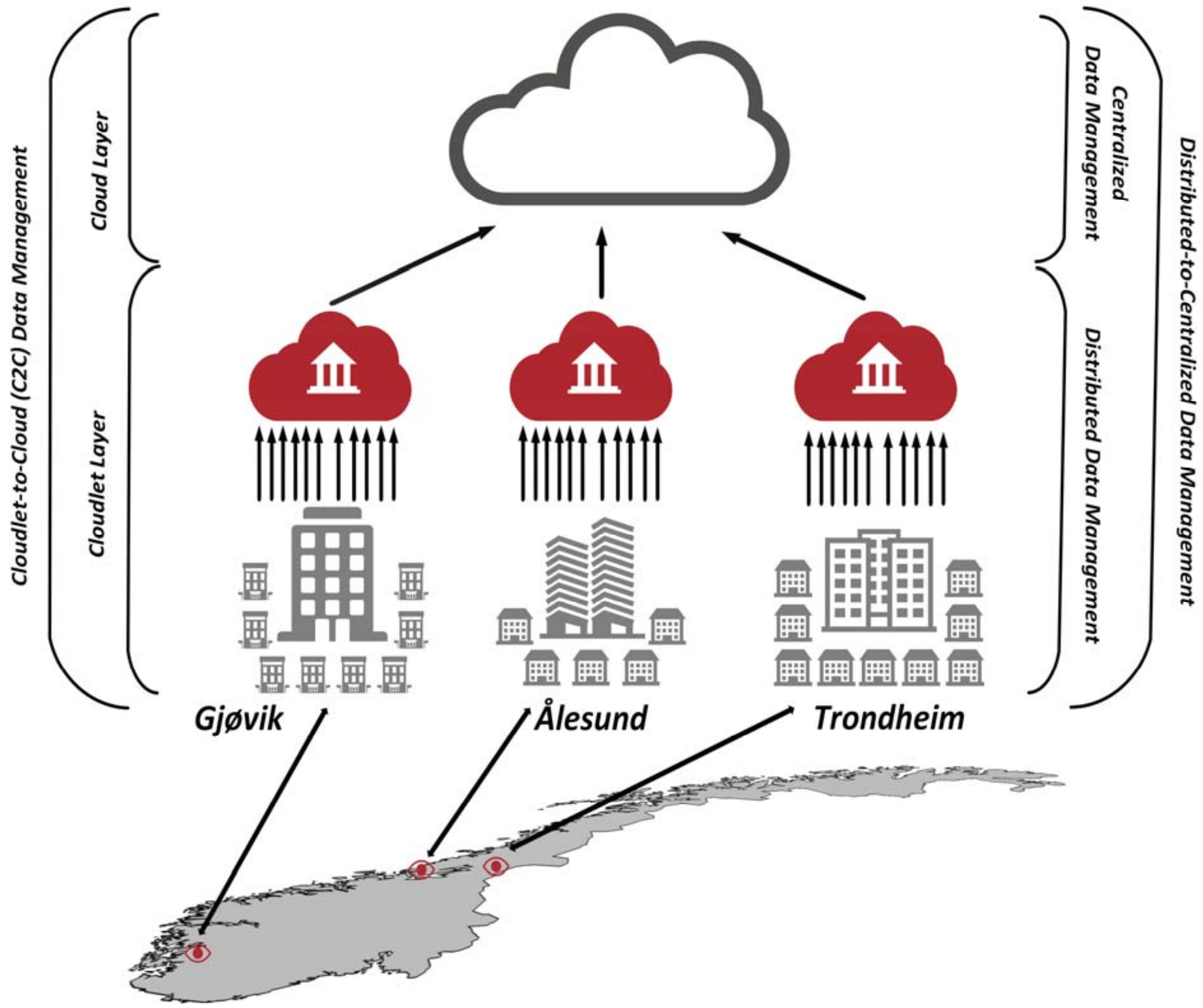

Fig. 1. D2C-ICT architecture and their c2C-DM architecture in multicampus university

C. Blockchain technologies through c2C-DM architecture for NTNU University, Norway (multicampus university)

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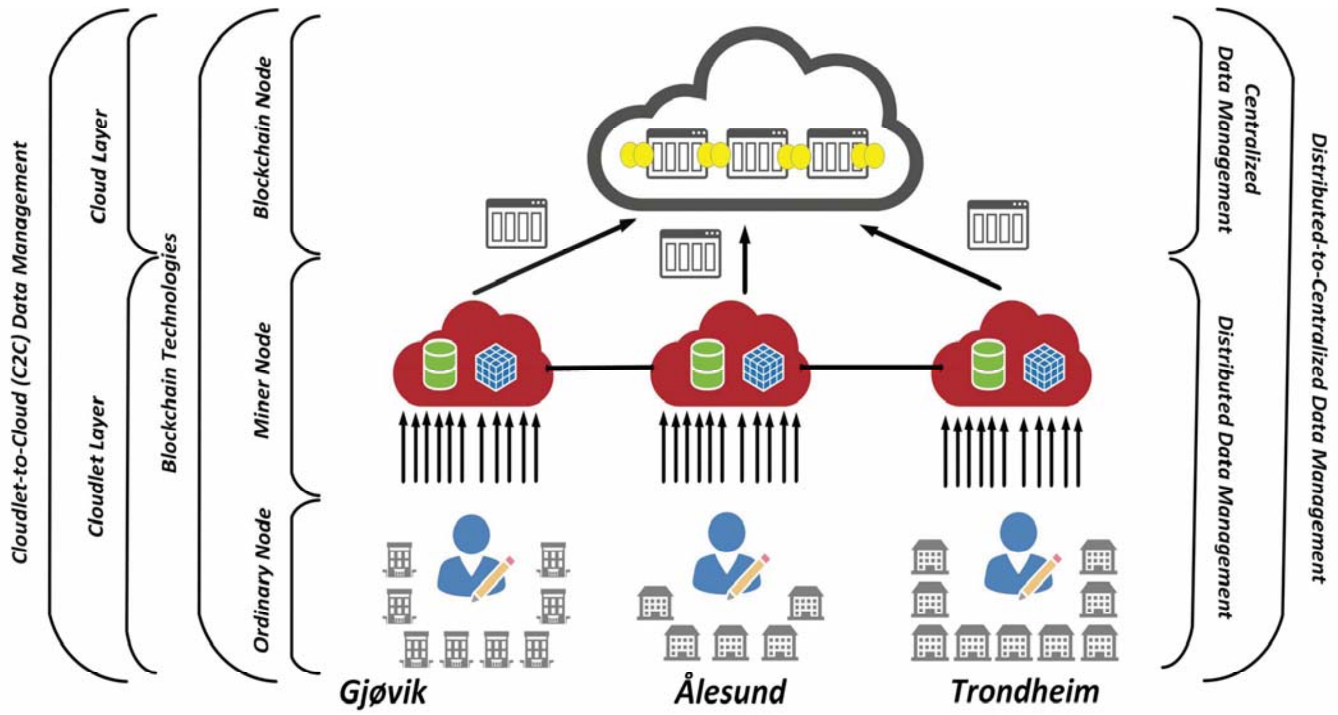

Fig. 2. Integration of D2C-ICT architecture, blockchain technologies and c2C-DM architecture through multicampus university scenario

VI. Conclusion And Future Direction

This position paper's main contribution is diverse for large-scale IoT network management in smart cities. This position paper discussed our initial proposal about the further possible contribution and implementation of ICT architecture and its data management through blockchain chain technologies in smart cities' large-scale IoT networks. We believed that blockchain technologies could be useful for data management (including data filtering and aggregation) through blockchain consensus algorithms in multilevel ICT architecture from edge to cloud orchestration. To apply our initial thought to smart city business domains, we use the multicampus university scenario in Norway.

As part of the direction of our future work, we will explore more options related to data aggregation and continue developing other data life cycle phases of our proposed data management architecture through blockchain technology (including data security, data quality, etc.). In addition, we will also extend further details about blockchain structure and their related data structures (including Hash tables, Merkle root, etc.).

Acknowledgment

The first author of this paper aware of the publication's "ethical and requirements" rules based on the related section of "Ethical Requirements - Definition of Authorship" available on this page, https://conferences.ieeeauthorcenter.ieee.org/author-ethics/ethical-requirements/, and he always has full respect for the "*definition of authorship*" and the co-authors "*significant intellectual and effective contribution*" activities in all his collaborative papers. So, the first author only got and extracted some basic and general definitions about the definitions of "*multicampus university*," including "*cross-campus*" and "*course management*" from the Centre for Excellent IT Education [53-54] through a few initial discussions duration of "25-November-2018" to "12-December-2018" with Prof. Rune Hjelsvold group (https://www.ntnu.edu/employees/rune.hjelsvold) and his early-stage Ph.D. student on that time (https://scholar.google.com/citations?user=FSetodYAAAAJ&hl=en&oi=ao), and their related "*draft,*" "*non-approved*," and "*non-finalized*" paper proposal by the group decision.

The first author has also written this paper within the Research Centre on Zero Emission Neighbourhoods in smart cities (FME ZEN). The authors gratefully acknowledge the support from the ZEN partners and the Research Council of Norway.

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