A Blockchain-based Architecture for Integrated Smart Parking Systems

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***Abstract*—In this paper, we introduce an integrated smart parking system. The proposed integrated smart parking system brings multiple parking service providers together under a unified platform aiming to provide one-stop parking information services to the commuters in a smart city. However, the adaptation of such a system is prone to tempering while a massive amount of data is shared among different parties which raise concerns related to trust and performance. To address this challenge, we propose a blockchain-based architecture specific to the integrated smart parking systems. Finally, we present a set of design principles which shows the applicability of our proposed blockchain-based integrated parking system.**

***Index Terms*—Blockchain, smart parking, smart city, trusted system.**

I. Introduction

In recent years, city planners and practitioners have experienced enormous challenges in managing urban parking facilities to reduce the congestion and wasted land use while drivers cruise for finding a desired, nearby and reasonable parking location [1]. It also raises the fuel consumption which is harmful to the atmosphere due to high levels of carbon emissions. A lot of effort has been given to build efficient parking solutions. Despite, the urban travelers often find it difficult and challenging to secure a parking spot of their preferences. For instance, a person who is searching for a parking location from a specific parking service provider may fail to find one which triggers recurrent searching for another place. This is not only time consuming but also frustrating for the drivers. In addition, the user needs to be present physically to look for the vacant parking spaces. Sometimes they need to pay high parking rates while there are parking spots available in a little further distance. In order to address these problems, urban citizens would like to search for an application where they can find all parking information under a common platform in an integrated manner.

The proliferation of pervasive devices in smart cities has enabled the development of many smart mobility applications [2]–[4]. Smart parking is one of the innovations that provides easy to use parking services to the urban commuters by leveraging pervasive sensors and flexible payment systems. However, the current smart parking solutions are not too smart to meet the information needs of the city travelers. For instance, there is no such system which can provide personalized information related to parking facilities (e.g. parking availability, price, distance).

This complex problem can be addressed by integrating all the parking facilities under a single platform. However, infrastructure integration is regarded as one of the main challenges to provide efficient urban services for various reasons [5]. Most of the parking providers use their own business strategies in a city, and they dont want to share their own commercial policies with others. We identify two challenges of integrating the smart parking systems. Firstly, the lack of necessary mutual trust among parking service providers. Parking service providers have to upload their parking space information and offers into the integrated system. As a result, a parking service provider reveals its sensitive business information to the integrated system. In general, the integrated system is managed by a central authority. The central authority can be biased to a particular parking service provider. Therefore, the integrated system cannot be trusted [6], [7]. Moreover, an intruder can invade the system and temper parking-related data to hamper the smooth operation of the system. Secondly, the integrated system is susceptible to a single point of failure.

The cloud computing technology can be utilized to build a fault-tolerant system. However, the issues related to trust still exist. The parking data stored in the cloud can cause privacy breach of sensitive information [8], [9]. For instance, the disclosure of parking offers to rival parties can disrupt the entire business model. In order to overcome the aforementioned challenges, a novel system is required that offers trust and data integrity for the integrated smart parking systems.

Our research proposes a novel blockchain-based architecture for the smart parking system that offers trust and data integrity among parking service providers. The blockchain is widely acknowledged as a disruptive innovation that has the potential of redefining finance, economics and even the macroscopic societal systems [10], [11]. In fact, blockchain is an emerging decentralized architecture and distributed computing paradigm originally designed for cryptocurrencies [12]. The primary advantage of the blockchain technology is that it can be summarized as a decentralized and trusted model [13]. The technology relies on the peer-to-peer [14] networking concepts. In addition to the blockchain-based architecture of the smart parking system, we present a set of design principles which shows the applicability of our proposed blockchain-based integrated parking system. To the best of our knowledge, this paper is the first approach of integrated smart parking system that leverages the blockchain technology.

The rest of the paper is organized as follows. In section II, we discuss and summarize the limitations of the existing smart parking solutions. We present an overview of our proposed blockchain-based integrated smart parking system in section III. A layered architecture for the system is discussed in section IV. In section V, we discuss the detailed work-flow of the proposed system. Section VI lists and discusses the key design principles of our devised architecture. The paper concludes in Section VII with a direction to the future works.

II. Related Work

Several parking solutions are available in the market. However, most of them are not effective enough to provide personalized smart parking services. The use of IoT devices to control and monitor the overall parking system is expanding rapidly. Abhirup Khanna and Rishi Anand proposed an architecture in [15] which leverages IoT devices and TCP/IP protocol for exchanging parking data. Besides, they hosted the application in a centralized server which is always prone to a single point of failure. Another smart parking system has been proposed in [16] which utilizes RFID enabled IoT devices. This paper also implemented a light-weight cryptography algorithm to reduce computational cost and energy consumption during the handling and manipulation of user-sensitive information. However, this model was not built to establish and manage interconnection between two parking centers. Rachapol Lookmuang et al. proposed another smart parking model in [17] which aims to reduce trafficking in the parking area. The researchers used IoT devices along with computer vision techniques to find the parked vehicles using a mobile application.

There are many applications exist that help users searching and finding the nearest parking location from the drivers' point of drivers view. By using cloud computing and real-time information, Ajay Zajam and Surekha Dholay have conducted research to find out an efficient and nearby parking location [18]. Based on real-time traffic data, the researchers devised an algorithm which would identify the best route between the user and the nearby parking location. An IoT based parking reservation system called 'BlueParking was implemented in [1]. By using the proposed algorithm, users can find out suitable routing path for their destinations. By analyzing the congestion of location nodes, their traffic estimator service can automatically represent the status of different roads. Chia-Ying Lin et al. presented another model from the city planners point of view instead of drivers point of view in [19]. The idea is to manage the parking locations around the city to improve the utilization of the overall parking spaces.

Recent research has highlighted that several types of attacks can happen to compromise the data generated from IoT devices [20]. Ioannis Chatzigiannakis et al. have proposed a model for parking system using IoT data and elliptic curve based security platform [21]. The authors used the Elliptic Curve Cryptography (ECC) algorithm for securing the data. They also built a generic architecture which can run on the different operating systems. However, the integration of data from different parking service providers in a common platform was not addressed by the researchers.

Because of the unavailability of the frameworks which can integrate data with public auditability without a trusted third Party, Bin Liu et al. proposed a blockchain based framework [22] which can ensure transparency and data integrity. This framework resolves the problem of dynamic data integrity verification in a fully decentralized environment and makes it more reliable. However, the parking centers are not integrated under a unified model to provide personalized parking information services to the users. A Bayesian inference model for preserving data integrity and data manipulation is proposed in [23]. Chin-Ling Chen and Wei-Cheng Chiu have tried to integrate different parking system in one platform [24]. The researchers integrate different parking centers in a centralized system where third-party management manages the data which may cause loss of transparency for different transactions.

Our analysis of existing research works found that the main aim of current research on smart parking is mainly focused on providing the users a parking location from a single parking service provider. Several research projects highlight the security issues and they apply some approaches to mitigate different types of attacks that can happen in a centralized structure. There are several studies that introduced the concept of decentralized parking system to resolve the data integrity issues. In comparison with the recent works, we propose an integrated smart parking system where the main aim is to connect all the parking service provides under a unified platform. While most of the existing solutions deal with the smart parking problem in a centralized manner which involves a trusted third party and cant provide enough lucidity, our proposed system produces transparency and it is mostly inviolable because of the decentralized infrastructure.

III. Overview of the Proposed System

In this section, we present an overview of the proposed blockchain-based integrated car parking system. There are three participants in our proposed system: *parking service provider*, *blockchain network*, and *user*. The parking service provider offers *parking-as-a-service*, updates parking space, and offer (i.e. cost) information in the integrated system. The blockchain network contains a public ledger and updates the public ledger with the valid transactions only. A consensus mechanism is used to verify the transactions. The parking user is the participant who requests for a car park. The integrated smart parking system provides separate application interfaces for each of the participants for communicating with it. Figure 1 illustrates our proposed blockchain-based integrated smart parking system.

Assume that there are several smart car parking available in the city under multiple car parking service providers. For simplicity, assume that each smart car park is under a single service provider. Every parking area is connected to a

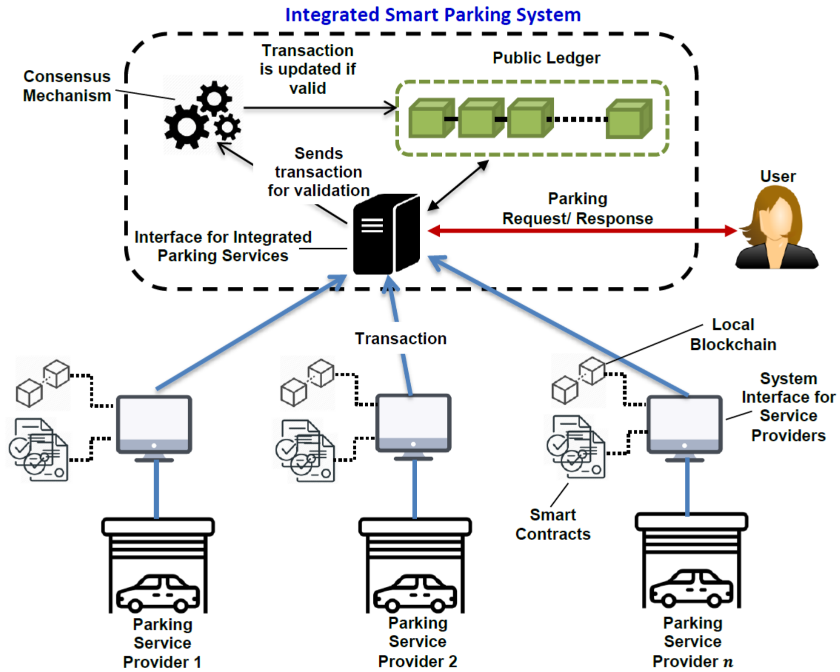

Fig. 1. Overview of Integrated Smart Parking System

blockchain-based integrated smart parking system. Generally, every parking area has a local copy of ledger (i.e local block). There can be two types of *transactions* in the system. First, the data generated by the parking sensor. Assume that each parking area in a smart car park is equipped with an IoT device (e.g. parking sensor) that can generate car parking availability as *transaction*. Each car parking service provider has a *smart contract* to generate the transaction. If a parking area is changed from ”vacant” to ”occupied”, the corresponding IoT device generates a transaction. Similarly, the IoT device generates a transaction when the parking area is changed from ”occupied” to ”vacant”. The transaction is first sent to the local block. The local block sends the transaction in the blockchain network for verification. Second, data related to parking prices. Assume that parking service providers set a price of parking based on the time. They create smart contracts for parking prices. The smart contract for the parking price is transferred to the blockchain network. Whenever a parking price is changed dynamically based on the time, a transaction is generated. The transaction is sent to the blockchain network for verification. Next, the transaction is verified by the blockchain network using a *consensus mechanism*. If the transaction is valid, then it is stored in the public ledger. Consequently, all of the local blocks are updated.

IV. Layered Architecture of the Proposed System

In this section, we present a layered architecture of our proposed integrated smart parking solution based on the blockchain technology. The proposed layered architecture characterizes and standardizes the typical architecture of the blockchain based integrated smart parking systems. Additionally, the architecture presents major components of the system. Our architecture consists of four layers: *application layer*, *network layer*, *transaction layer*, and *physical layer*. An illustration of the layered architecture is provided in Figure 2.

A. Application Layer

The application layer is the top layer of the architecture stack which enables a participant's interactions with the system. Using a mobile phone application (i.e. Android or iOS) or web application, users can search their preferred parking locations and can make the reservation. Similarly, parking service providers can send their parking-related information (e.g. availability of parking spaces and offers) to the integrated system. From the application layer, a user connects to the blockchain network and can place their requests to the integrated parking system using an application. The integrated system is responsible for suggesting a suitable parking location depending on the user's choice and availability. Since users interact with the integrated system directly, this layer delivers the final service to the end users.

B. Network Layer

The network layer ensures communication among different parking centers, integrated system, and users. The data from the users and parking centers will be transmitted to the integrated system through this layer. This layer will contain different types of communication technologies including LAN and WAN which will be used by the users, parking service providers, and IoT devices related to the parking system (e.g. parking sensors and security cameras). The network layer brings distributed public ledger and content services seamlessly to the stakeholders doorstep as part of the standard offering. It contains various wireless communication technologies (e.g., Lora, Bluetooth, Wi-Fi, etc.) along with currently available GSM technologies such as 4G and 5G. This layer ensures the scalability as well. Giving an example, this allows adding and removing stakeholders dynamically to and from the integrated system. The network layer ensures the physical layer security of the system as well.

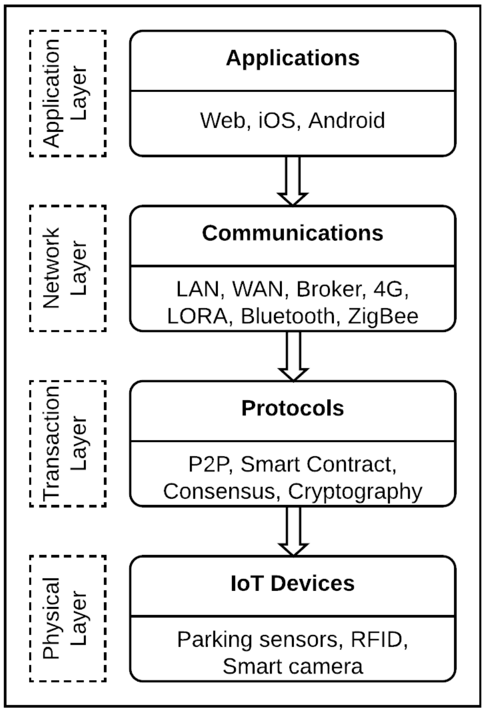

Fig. 2. Layer Architecture for Integrated Smart Parking Solution

C. Transaction Layer

Transaction Layer is responsible for transaction among the nodes in the network. This will also provide all the consensus mechanism of the entire blockchain network. The users and different parking centers will exchange data in a secure way using smart contract and consensus mechanism. Parking center will also update the public ledger through this layer. This layer communicates with the core blockchain network through the interface of the integrated system. Additionally, this layer validates new transactions. Moreover, the transaction layer preserves the transaction transparency and secure the data transmission without the use of a trusted third party. In terms of P2P based distributed architecture, we can remove central points of failures and bottlenecks of the system. Furthermore, blockchain will treat users data exchanges as transactions and validated by smart contracts. In this way, users information would remain immutable and distributed over time through blockchains cryptographic mechanism.

D. Physical Layer

The physical layer is the combination of different types of IoT devices. All of these devices are integrated into one common network through a p2p network protocol. Different types of sensors and actuators are the main element of this layer. Moreover, there will be some embedded technologies, such as raspberry pi and Arduino, along with some WSN devices. IoT device's data will be transmitted to the parking center server with the use of the transaction layer. Then the p2p network will be connected with the parking center servers and will update the public ledger. Additionally, this layer enables sensor and actuators data traceability and accountability over the p2p network. Since reliability is the key aspect of our proposed system, by taking advantage of the blockchain, secure-immutable storage, data can be safely and securely transmitted from the IoT devices. Using the IoT device sensors, a particular parking space availability will be recognized from the physical layer. With the use of cryptography, the user will be verified and vacant parking information will be updated in the public ledger. The cryptography verification method in the transaction layer will be processed by the smart contract. To reserve a parking space, the user can make a request from the application layer and the request will be processed through the network layer. To handle the user request, parking provider will use the network layer to make an interaction with the transaction layer. Finally, using consensus mechanism protocol from the transaction layer, individual parking provider will update the distributed ledger.

V. Proposed System Work-flow

In this section, we illustrate how our proposed model would work towards an integrated smart parking system.

The users of our system will be able to interact with the integrated parking system using an application which could be a smartphone application or a website. The users will search for their desired parking spaces using the application. Since all the parking service providers in the city will be interconnected using blockchain and p2p technology, the application will automatically suggest the nearest parking center for user selection. Then the user will make a request to the parking center server from his/her search. The parking center would respond with an acknowledgment and will build a connection. Algorithm 1 describes a detailed work-flow of the search and request processing mechanism of proposed system architecture. We can see from Algorithm 1 that a reservation request to a particular parking service provider initiates a local search for parking availability. If there is an available parking space, a booking is conducted and the public ledger is updated. In case of unavailability of a local parking spot, a search is conducted through the public ledger to find the alternatives. If no alternatives are available in the public ledger, the user is informed through an unavailability notification.

According to the design principle of our system, the parking centers will act as a data owner. While constructing a handshaking connection, blockchain should be started on each

Algorithm 1 Search and Request Processing

INPUT: Search for parking space, Select the desired parking center from the suggested list
OUTPUT: Reserve a parking space requested by the user, Update the public ledger

```
foreach reservation request do
    Look for available space in own server
    if space available in own server then
        Reserve for user
        Update public ledger
    else
        Search in the public ledger    ▷ Alternate parking
                                       ▷ provider
        if Space available in public ledger then
            Reserve request with the hash
        else
            No parking Space available
        end if
    end if
end for
```

Algorithm 2 Parking Provider Operations in Public Ledger

INPUT: v : - Number of Vacant or Occupied spaces of a parking provider.
OUTPUT: $\mathcal{V}$: - a set $\{v_1, v_2, ...v_n\}$ of all available spaces in a smart city.

```
foreach Parking Provider P_i do
    v_i ← Vacant Spaces
    if vehicle in then
        v_i ← increment
    else if vehicle out then
        v_i ← decrement
    end if
    if Authenticate with Smart Contract then
        if P_i in P2P Network then
            𝒱 ← 𝒱 ∪ v_i         ▷ Update Public Ledger
                                ▷ Data Transaction
        end if
    end if
end for
```

participating user and parking center. After constructing two-way handshaking, a smart contract will be created by the user with a digital signature. As the parking center will interact with each other through the smart contract, all the transactions on the whole chain can be transparently audited. Once the blockchain service starts, then blockchain data on a node will be synchronized.

As per the validation of data, it is going to be encrypted by the hashing algorithm and this is almost impossible for an unauthorized attacker or hacker to attack the network. Since the parking center has a copy of the public ledger using which it will easily decrypt the parking provider request as the public key stored in the ledger. If the decrypted hash is matched with the protected hash then the provider will count as a valid user of the network. The updated vacant spaces (v_i) will be synced with the public ledger by a valid service provider (P_i). Otherwise, the transaction will be interrupted. Finally, using all the parking centers available spaces the public ledger will be updated. The set of all available spaces ($\mathcal{V} = \{v_1, v_2, ...v_n\}$) will be incremented($v_i$ increases) or decremented(v_i decreases), while a vehicle will release or reserve the parking spaces from the parking center.

Since all the parking centers in the city will be using the Peer to Peer network and all the p2p function verification method are known by each parking center, each parking center will have a copy of the updated public ledger. A parking center will search for available space for parking from the ledger, then it will notify the user. After that notification, the user will reply to the parking center with an acknowledgment. Using that acknowledgment, the parking provider will make a transaction in the public ledger as per its own policy. While finishing the transaction, it will be added to the public ledger will be updated according to the Algorithm 2.

If no free space found in the selected parking center, then the parking center will search on the public ledger for an available space of nearby parking center. If the free space found in the public ledger, then the parking center will notify the nearby parking center. With the confirmation of user, the parking center will request to that parking center for reservation. After that, the alternate parking center will response and make a transaction in the ledger using own business policy. Hence, the user will get the facility of an integrated parking system. Therefore, different parking centers can be integrated without publishing their own business policies and no need to trust a third party.

VI. Design Principles

This section discusses the required design principles for our proposed system.

- Decentralized process: The primary objective of utilizing blockchain is to implement a decentralized framework which can overcome the faults created by the centralized system. Furthermore, decentralized record or database and smart contracts guarantee the secured data transmission or exchange. The system assures the security with the use of smart contract and public ledger, which make it quite impossible to access personal or other business policies and confidential information. However, blockchain integration and decentralization process will be able to make the communication process trustworthy and smart enough with the collaboration of different parking center.
- Privacy and security: Owing to the integration process, the parking business holders will face the problem of exposing the business strategy related information which will create data integrity and privacy issue. The parking providers will not have any complexity to maintain their

business with our proposed system. Additionally, only the authorized parking provider can change his own data in the ledger with the use of a private key and the data will remain immutable over time in the blockchain. However, parking provider only can access the vacant space information of other parking providers from the ledger, so, there will be no chance of data leakage while a parking center will suggest another parking center.
- Process Management: To implement the integrated parking system, a decentralization process is required. The decentralization process can confirm an efficient, responsive and reliable system. The proposed system imposed a layered architecture, which maintains the interaction process that transmitting data to the distributed ledger using the request of a user or parking provider. Finally, heavy usage of cryptography and hashing mechanism in the blockchain network ensures the proposed smart parking system a *trustless* system. The trustless system indicates that the participants can execute a transaction without the need of a trusted third party.

VII. Conclusion and Future work

This study developed a model to provide smart parking solution based on infrastructure integration mechanism using blockchain technology. We devised a layered architecture which facilitates data integrity and trust among different stakeholders in an integrated smart parking scenario. Through this model urban drivers can find a reasonable parking place of their preference. Also, the parking service providers can share their sensitive data without a trusted third party. This model is especially focused on security and privacy enhancement. Blockchain technology has already made a significant impact in the field of decentralization with cryptography. With the help of blockchain mechanism, our model acquires the trust of the parking centers and users while all the stakeholders interact with smart applications. Since the smart contract features ensure data privacy and security, the users will trust the system.

Our proposed model avoids transmitting personal or business strategy related information through a trusted third party. Therefore, it will be suitable for a situation where non-trusted networks are appended in the integrated infrastructure. We describe our system with a layered architecture and a workflow which make it visually more factual. Overall, the presented work-flow ensures the secured network for an integrated smart city parking system. In the future, the system proposed in this paper requires a rigorous implementation with real-world data datasets to check it's scalability.

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