Abstract

The increased density of the urban population and frequent transportation movement has lead to parking issues in these areas. Many efforts have been made to efficiently utilize the existing parking facilities. Most of these solutions target the large-scale private and public parking facilities; however, the individual parking facilities are not much explored and exploited for reducing the parking issues. In the last few years, the Online-to-Offline (O2O) model has witnessed huge attention from the research community due to its versatile applications in many domains. The main objective of the O2O model is to create service awareness online, allowing potential users to review different offers and then visit local physical places for purchasing. The security of the users’ data has always been considered a crucial factor in any public sharing platform. The [blockchain](https://www.sciencedirect.com/topics/engineering/blockchain) model has been regarded as a solid security platform for many public sharing platforms. This work designed a [blockchain](https://www.sciencedirect.com/topics/engineering/blockchain) framework with a novel data verification and role-based Access [control method](https://www.sciencedirect.com/topics/computer-science/control-method) for securing the parking [service data](https://www.sciencedirect.com/topics/computer-science/data-services). Several experiments are performed using the sawtooth blockchain tool to investigate the performance of the proposed blockchain framework against the baseline approach concerning latency, meantime testing (MTT), throughput, transaction [sending rate](https://www.sciencedirect.com/topics/engineering/sending-rate) (TPS), and average response time (ART). The obtained results confirm that the proposed approach is scalable and feasible for smart parking and other IoT-based applications.

城市人口密度的增加和频繁的交通流动，导致了这些地区的停车问题。为了有效利用现有的停车设施，人们做出了许多努力。这些解决方案大多针对大规模的私人和公共停车设施；然而，个人停车设施在减少停车问题方面并没有得到很多探索和利用。在过去的几年里，在线到离线（O2O）模式由于其在许多领域的广泛应用而受到了研究界的极大关注。O2O模式的主要目的是在网上创造服务意识，让潜在用户审查不同的报价，然后访问当地的物理场所进行购买。用户的数据安全一直被认为是任何公共共享平台的关键因素。区块链模式已经被认为是许多公共共享平台的坚实安全平台。这项工作设计了一个区块链框架，它具有新颖的数据验证和基于角色的访问控制方法，以确保停车服务数据的安全。使用锯齿区块链工具进行了一些实验，研究了所提出的区块链框架与基线方法在延迟、时间测试（MTT）、吞吐量、交易发送率（TPS）和平均响应时间（ART）方面的性能。获得的结果证实，所提出的方法对于智能停车场和其他基于物联网的应用是可扩展的和可行的。

Introduction

In the last few years, urbanized areas have seen huge development and population density has increased at an immense rate. This increase in the population has led to the problems of urban planning management, transportation management, and parking issues for people traveling to the urban areas. The parking issues lead to time, effort, and resource wastage. The existing public and private parking facilities are limited to handle such large parking requirements. The urban parking management [1], [2], [3], [4] not only reduces drivers’ searching time for parking, reduces the congestion of traffic, and diminishes the air pollution but also leads to parking lot efficiency and reduces the cost of infrastructure development.

在过去的几年里，城市化地区有了巨大的发展，人口密度也以巨大的速度增加。人口的增加导致了城市规划管理、交通管理和前往城市地区的人的停车问题。停车问题导致了时间、精力和资源的浪费。现有的公共和私人停车设施是有限的，无法处理如此大的停车需求。城市停车管理[1], [2], [3], [4]不仅可以减少司机寻找停车位的时间，减少交通拥堵，减少空气污染，还可以提高停车场的效率，降低基础设施建设的成本。

In most of these areas, the residential people have set up their parking facilities in which some of the parking places are also equipped with Electric Vehicle (EV) charging and car wash facilities. Some of these parking places are free most of the time and other parking places are free in different time slots. Previously, many studies are conducted to utilize the existing public and private parking slots efficiently and also equip the existing parking lots with smart technology [5], [6], [7], [8]. These solutions are developed to facilitate the users in parking reservations in a cost-efficient way and improve the utilization of the existing parking facilities [9], [10]. However, no or little attention has been paid to utilize most of the idle parking slots of the individuals and incentives them as per use of their parking facilities. Recently, the online to offline (O2O) has emerged as an important component of the Industrial Revolution 4.0 [11]. The O2O technology encompasses physical (offline) and advanced technology (online) to offer a new experience of services. The users can order or reserve the services using their smartphones on the go and then collect the items accordingly. The O2O model has shown keen interest in various applications including food delivery, Vehicle sharing, lodging, etc. The O2O service model is the best sharing platform for various applications and currently, researchers and industry are developing new O2O services. The O2O service model is not only useful for large-scale industries but also considered a potential platform for small and medium industries and marketplaces [11]. In this work, we proposed an O2O parking sharing model where individuals or public/private parking service providers can register their parking facilities and the users can avail the parking services on the go [12], [13]. The proposed model provides various services including parking reservation, navigation, optimal route guidance, payment, etc. The user can register and share their parking facilities and are paid on an hourly basis. As the O2O parking sharing model is publicly available and any individual has access to the system thus the security of the user data is always at risk.

在大多数地区，居民已经建立了他们的停车设施，其中一些停车位还配备了电动汽车（EV）充电和洗车设施。其中一些停车位大部分时间是免费的，其他停车位在不同的时间段是免费的。以前，许多研究都是为了有效地利用现有的公共和私人停车位，也为现有的停车场配备了智能技术[5], [6], [7], [8]。这些解决方案的开发是为了方便用户以具有成本效益的方式预订停车位，并提高现有停车设施的利用率[9], [10]。然而，没有或很少有人注意到利用个人的大部分闲置停车位，并根据其停车设施的使用情况进行奖励。最近，线上到线下（O2O）已经成为工业革命4.0的一个重要组成部分[11]。O2O技术包含了物理（离线）和先进技术（在线），以提供一种新的服务体验。用户可以在旅途中使用他们的智能手机订购或预订服务，然后领取相应的物品。O2O模式在各种应用中表现出浓厚的兴趣，包括食品配送、车辆共享、住宿等。O2O服务模式是各种应用的最佳共享平台，目前，研究人员和行业正在开发新的O2O服务。O2O服务模式不仅对大规模产业有用，而且也被认为是中小型产业和市场的潜在平台[11]。在这项工作中，我们提出了一个O2O停车共享模式，个人或公共/私人停车服务提供商可以注册他们的停车设施，用户可以利用停车服务，在旅途中[12], [13]。该模型提供各种服务，包括停车位预订、导航、最佳路线指导、支付等。用户可以注册并分享他们的停车设施，并按小时付费。由于O2O停车共享模式是公开的，任何个人都可以访问该系统，因此用户数据的安全始终处于危险之中。

For the last few years, blockchain-based approaches are widely adopted for various security services including health, industry, energy trading, etc. [14], [15]. Like other services, Blockchain-based solutions are also employed for the integrity of the information. The Blockchain (BC) approach is scalable and has the potential to ensure the security of various transactions in a decentralized manner by providing authority to each participant for transaction authentication. Every transaction in the blockchain network is signed and ultimately verified by each legitimate network participant. The cryptographic hash algorithms are used to ensure the integrity of the transactions and the mining nodes are responsible for signing and verifying transactions and maintaining the blockchain ledger consisting of chained blocks of transactions [16], [17], [18], [19]. All these features of the blockchain lead to transactions that are immutable and altering any transactions is not possible. Thus in this work, we proposed a blockchain-based scalable model for the O2O parking sharing platform.

在过去的几年里，基于区块链的方法被广泛采用于各种安全服务，包括健康、工业、能源交易等。[14], [15]. 与其他服务一样，基于区块链的解决方案也被用于信息的完整性。区块链（BC）方法是可扩展的，并有可能通过向每个参与者提供交易认证的权力，以分散的方式确保各种交易的安全。区块链网络中的每一笔交易都会被签署，并最终由每个合法的网络参与者验证。加密哈希算法被用来确保交易的完整性，采矿节点负责签署和验证交易，并维护由交易链块组成的区块链账本[16], [17], [18], [19]。区块链的所有这些特点导致交易是不可改变的，改变任何交易是不可能的。因此在这项工作中，我们为O2O停车共享平台提出了一个基于区块链的可扩展模型。

The motivation and novelty of our proposed work is discussed as follows:

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The increased density of the urban population and frequent transportation movement has lead to parking issues in these largely populated areas. Many parking services [3], [4], [8], [9] have been developed that often target private and public parking facilities; however, there is a need to develop a decentralized and automated parking solution that mainly targets the parking areas owned by the smart city citizens which are most of the time idle. To the best of our knowledge, this is our novel contribution to develop an O2O-based parking sharing service.

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The security of the users’ data has always been seen as a crucial factor in any public sharing platform. The blockchain model has been considered a solid security platform for many public sharing platforms. This work designed a blockchain framework with a novel data verification and role-based Access control method for securing the parking service data.

The paper is further organized as follows: Section 2 presents the literature review concerning smart parking sharing systems, O2O service models, and finally the blockchain-based parking solutions. The proposed O2O blockchain framework with novel data verification and role-based Access control method is discussed in detail in Section 3. The experimental setup and performance investigation are delineated in Section 4 followed by the Conclusions and future work.

Section snippets

Related work

The advancement in technology has led to the design and implementation of various smart applications. Cyber–physical systems (CPS) are quite useful in providing various services to users. Technology plays the role of connecting the consumers to the service providers. In the last few years, various solutions are in place for providing parking service provisioning. The technology and CPS [7] is useful in allowing the drivers to find the parking slots efficiently. In [9], the authors designed a

Design of proposed solution

The proposed system is divided into two main modules namely Service Agent and Blockchain Agent as shown in Fig. 1. The discussion about each of the modules is presented as follows.

Test bed setup

The performance evaluation can be performed in three different ways that are experimental, analytical, or simulation approaches. The experimental setup is costly and difficult to configure due to the complexities involved in setup and execution. However, experimental approaches provide a more real performance evaluation of the compared approaches. The analytical approaches are easy to deploy; however, they are unable to grasp some of the important characteristics for performance evaluation. The

Conclusions and future work

This work proposed a blockchain-enabled O2O-based parking sharing service that provides reliable parking searching and reservation service. The proposed blockchain efficiently manages the parking data ensuring scalable service provisioning through the off-chain scaling. The performance evaluation of the proposed approach is carried out against the baseline approach and extensive experiments are performed to see the behavior of the proposed blockchain approach. The complexity analysis of the

CRediT authorship contribution statement

**Muhammad Ibrahim:** Conceptualization, Methodology, Writing – review & editing. **YunJung Lee:** Supervision, Software, Data curation, Writing – original draft. **Suyeon Kim:** Software, Validation, Writing – review & editing. **Do-Hyeun Kim:** Conceptualization of this study, Methodology, Software.

Declaration of Competing Interest

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to <https://doi.org/10.1016/j.compeleceng.2022.108267>.

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