Integrated Services for Passenger Transportation in Smart Cities Based on Blockchain

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Abstract. This paper investigates the integration of blockchain technology into passenger transportation systems in smart cities, focusing on a Mobility as a Service (MaaS) solution for passenger. The study highlights the potential of blockchain to enhance integrated payment and ticketing systems, enabling efficient interactions among diverse transportation methods such as buses, trains, bike-shares, and ride-hailing services. This integration aims to streamline user experience and align with urban objectives of efficiency, environmental sustainability, and enhanced data security.

Keywords: Blockchain, Smart Cities, Multimodal Transportation, Mobility as a Service (MaaS), Urban Mobility.

1 Intoduction

In today's smart cities, the integration of cutting-edge technologies into urban infrastructures is critical [1], particularly for enhancing transportation systems that cater to both passenger and freight movements. The concept of multimodal transportation is at the heart of this evolution, combining diverse transportation methods within a cohesive network to significantly improve urban mobility and logistics. In this context blockchain technology emerges as a promising solution, offering a secure, transparent, and efficient framework for managing transactions and collaborations between various service providers and users in the transportation sector.

This paper explore the development and implementation of a blockchain-based Mobility as a Service (MaaS) solution dedicated to the transportation of passengers (and with potential extensions for logistics and transportation of goods). We focus on how blockchain can transform integrated payment and ticketing systems, facilitating efficient interactions among users and service providers, such as buses, trains, bike-shares, freight carriers, and ride-hailing services. Implementing such a system within a smart city framework not only streamlines the user experience but also aligns with broader urban objectives of efficiency, environmental sustainability, and enhanced data security.

The current research is also connected to the European Union's initiative to enhance urban mobility and logistics, primarily through its association with the DELPHI project. EU has introduced a call for projects under Horizon Europe, specifically under the reference HORIZON-CL5-2023-D6-01 with focus on fostering safe and smart mobility solutions. Under this call DELPHI project propose development of a solution to integrating passenger and freight transport in a single system aiming to deliver the enablers - both on technical and governance/ regulatory level, towards a federated network of platforms for multimodal passenger and freight transport.

The State of the Art section will present the blockchain technology in general and will survey the existing landscape of MaaS systems, pinpointing challenges in integrating blockchain into such systems. We will investigate how the key characteristics of blockchain, namely decentralization, transparency, immutability, and security, are ideally suited to address the needs of a MaaS system.

In the main body of the paper, we will provide analysis of the design and architecture of a blockchain-enabled MaaS system. The discussion will cover technical details of blockchain based solution and data model. Furthermore, we will tackle issues related to scalability to ensure the system is technologically robust.

The data model proposed in this paper, primarily focused on passenger transportation but in continuation of this research it will be expanded to include freight transportation. This extension aims to align with the DELPHI project's objectives, allowing for the use and tracking of public transportation infrastructure for goods transportation.

2 State of the Art

2.1 Blockchain Technology

Blockchain emerged from a proposal in 2008 [2] and was launched in early 2009. It operates as a public ledger, storing all committed transactions in a growing chain of blocks. Key traits of blockchain include decentralization, auditability, persistence and anonymity. Enabled by integrating technologies like cryptographic hash, digital signatures (based on asymmetric cryptography), and distributed consensus mechanisms, blockchain functions within a decentralized environment. This technology facilitates decentralized transactions, offering significant cost savings and efficiency improvements [3].

Blockchain operates as an ever-expanding collection of records, referred to as blocks, interconnected and safeguarded by cryptographic techniques. Employing the P2P (peer-to-peer) protocol, blockchain demonstrates resilience against single points of failure. Through its consensus mechanism, it establishes a universally accepted sequence of transactions and blocks, ensuring the reliability and uniformity of the blockchain among geographically dispersed nodes [4]. A Blockchain transaction represents a discrete component of an operation logged within public records, also called blocks [5].

The introduction of smart contracts in blockchain marked a milestone called Blockchain 2.0. Smart contracts refer to computer programs that operate within the blockchain network. These programs are capable of articulating triggers, conditions, and business logic, facilitating intricately programmable transactions [6]. The term "smart contract" was introduced by computer scientist and cryptographer Nick Szabo well before the emergence of the blockchain concept, in [7].

While Bitcoin stands as the most renowned application of blockchain technology, its utility extends far beyond cryptocurrencies. The inherent ability to facilitate transactions without reliance on banks or intermediaries enables blockchain to be applied across diverse financial services. This includes areas such as online payments, digital assets and remittance [8].

Blockchain stands ready to revolutionize other applications also, such as art sales through digital media transfer, supply chains, delivery of remote services like tourism and travel, and innovative platforms shifting computing towards data sources and distributed credentialing [9]. Furthermore, its scope expands to encompass distributed resources like crowdfunding, power generation and distribution, electronic voting, governance of public records, and identity management [10].

2.2 Blockchain in Public Transportation

The concept of Mobility as a Service (MaaS) in urban transportation, aiming to transition from individual vehicle ownership to accessing various transportation modes as a service, is discussed in [11] and [12]. As noted, such a system could also support and integrate transportation of goods. MaaS concept integrates various forms of transport services into a single, accessible, and user-centric platform. Blockchain technology can significantly enhance Mobility as a Service (MaaS) systems by providing a secure and transparent platform for transactions and data management across various transportation services. Its use of smart contracts and tokenization also enables seamless integration and user incentivization within the MaaS ecosystem.

Application of blockchain technology in implementing MaaS platform is explored in [13] with focus on performances under various load scenarios. Authors explore and analyze two well know and mature blockchain technologies: Ethereum platform based on permissionless technology and Hyperledger Fabric platform which is based on a permissioned technology. The conclusion of the study is that both platforms are suitable for implementing a MaaS platform, but the deployment environment should be carefully scaled and correlated with the estimated usage load. Additionally, the study indicates that Hyperledger Fabric exhibits some better performance compared to Ethereum.

Another approach is presented in [14] where authors use Hyperledger Indy [15] blockchain for implementing a multi-layered Blockchain framework for Smart Mobility Data-market (BSMD), addressing key challenges in privacy, security, management, and scalability in context of transportation smart mobility. They highlight the vulnerability of traditional data storage methods, such as central servers, to hacking and unauthorized sharing. The BSMD framework ensures secure and transparent transactions by allowing participants to share encrypted data on the blockchain, with transactions occurring under mutually agreed-upon rules.

Ref. [16] outlines challenges and potential solutions pertaining to the primary subsystems of public transportation services, particularly emphasizing the impact of such services within densely populated urban regions. The focus lies in identifying blockchain-based solutions aimed at evolving the current management platforms for future advancements in this domain.

3 Platform Design and Implementation

3.1 Functionality Overview

The proposed MaaS platform's main objective is to aggregate the payments made to transport companies from a city into a single application. By doing this, the platform can also store the details of the rides and provide both the transporters and transportees with meaningful statistics. Figure 1 presents the main use-cases of the proposed solution.

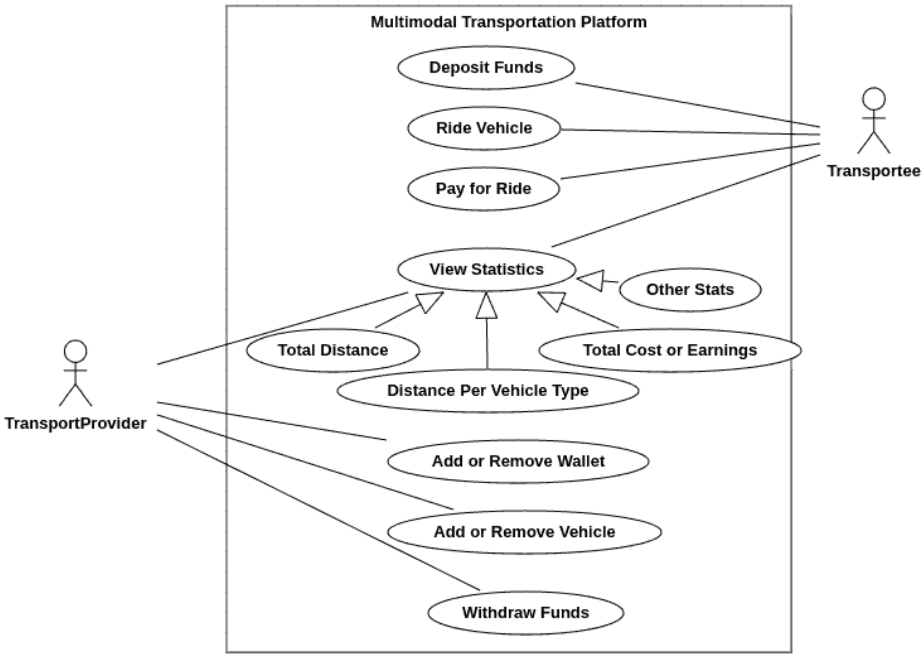

Fig. 1. The use-case diagram of the proposed platform.

The main actors (or users) of the proposed platform are the transport providers or companies and the entities that use the platform to commute, persons or packages that can be sent by using public transport. Because these two user types have access to different functionalities, they will access the platform through different interfaces (or client applications).

To enable payments through the platform both the transport providers and the transportees have virtual wallets. The transportee wallets will be funded through the deposit option. Once a ride is completed the transportee will make the payment, transferring funds to the transport provider wallet. These payments will take place internally, inside the platform. The deposits and the withdrawals are enabled through external payment providers.

Both types of users will be able to see statics such as: distance per time period, earnings, or costs per time period, distance per vehicle, distance per vehicle type, etc. For example, providing the transportees with data regarding the vehicle type can encourage them to favor companies with a more environmentally friendly fleet for future rides.

3.2 The System's Architecture

Figure 2 presents the system's architecture, detailing its main components. The system has three main components: the client applications, the platform's back-end and the distributed ledger or blockchain network.

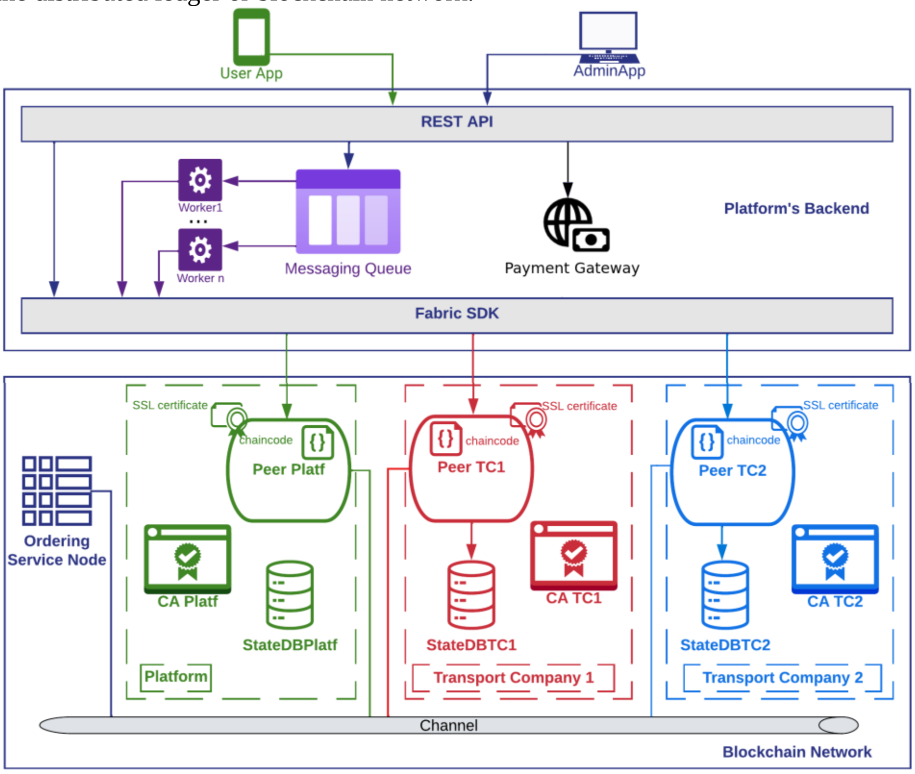

Fig. 2. The architecture of the system.

Client Applications. There are two client applications utilized to access the system. One mobile application is designed for the transportation users, while another web application caters to the transport providers. These applications enable users to access the platform's functionalities outlined in the preceding subchapter.

Blockchain Network. The platform's entire persistence layer relies on the blockchain, functioning as a distributed database. Various organizations maintain copies of the state and ledger databases within this blockchain framework, guaranteeing the immutability and security of stored data. Replicating data across multiple network nodes serves to bolster resilience against potential single points of failure. The chosen blockchain solution is Hyperledger Fabric.

The proposed architecture involves three participating organizations within the network. *Platform* functions as the legal entity overseeing the system, while *Transport Company 1* and *Transport Company 2* represent separate transport provider companies. Though participation is not obligatory, we highly advise each transport provider to engage in the network actively, contributing to the integrity and security of the shared data. As illustrated in the previous diagram, each organization operates its own peer, state database, and certificate authority.

Chaincode. It refers to the smart contracts or programs that define the business logic governing transactions on the blockchain network. It's the code that specifies the rules and procedures for interactions within the network, enabling the execution of transactions and the manipulation of the ledger's state.

Peer. A peer refers to a node within the network that maintains a copy of the ledger and smart contracts (*chaincode*). Peers play a crucial role in the network by endorsing transactions, maintaining the ledger, and participating in the consensus process.

Certified Authority (CA). It handles user certificate management tasks like user enrollment and cancellation. Hyperledger Fabric operates as a permissioned blockchain network, employing X.509 standard certificates to define permissions, roles, and attributes for individual users. Users can perform queries or initiate transactions through channels that align with their assigned permissions and roles.

State DB. The State Database refers to the database responsible for storing the current state of the ledger. The ledger in Fabric maintains a record of all transactions that have occurred, and the StateDB keeps track of the current state of all assets or data within the blockchain network.

Channel. A channel is a private and confidential line of communication between specific network members, allowing for the segregation of transaction data and confidential communication within a subset of the network.

Ordering Service Node, also known as the ordering node or simply the orderer, plays a crucial role in managing the process of grouping validated transactions into blocks, ensuring their consensus, and adding them to the distributed ledger.

Platform's Backend. The backend of the system is developed using Java (with Spring framework) and serves as an intermediary layer connecting the client application to the blockchain. It utilizes a messaging queue and a payment gateway to facilitate its operations.

ReST API. The platform's backend exposes a ReST API based on JSON for enabling the communication with the client applications.

Fabric SDK. The integration with the blockchain network was accomplished using the Java Fabric SDK.

Messaging Queue and *Workers.* Basic operations, such as ride payments or balance inquiries, are currently directly handled by the API using the Fabric SDK. However, more intricate tasks, like generating statistics, are decoupled through a messaging system (RabbitMQ). When a request of this nature is received, the API logs a record in the messaging service. Subsequently, a worker processes the message from the queue when available. The messaging queue helps in load balancing by distributing work among multiple workers. This scalability ensures efficient utilization of resources and prevents bottlenecks.

Payment Gateway. This component facilitates integrations with payment providers, allowing for fund deposits and withdrawals.

3.3 Data Model

Figure 3 presents the model of the data stored in the blockchain.

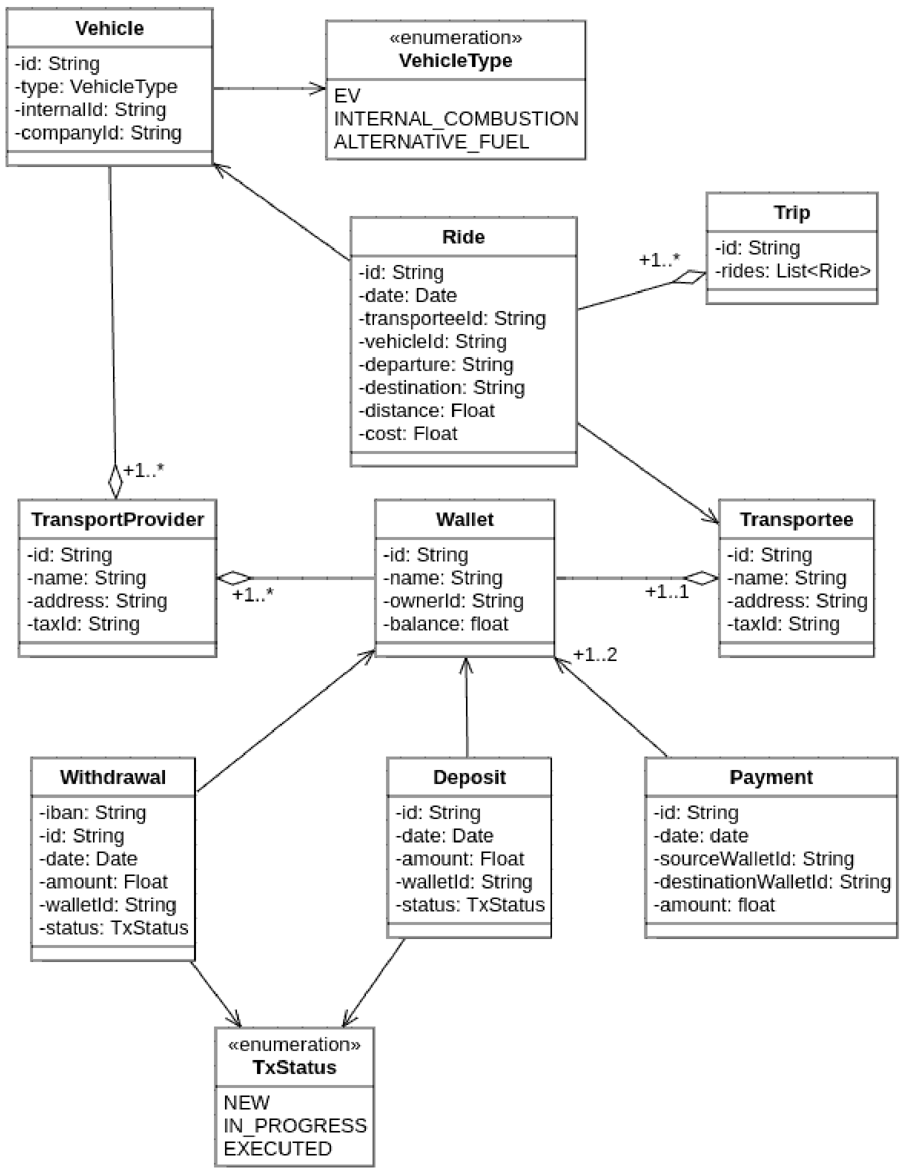

Fig. 3. The platform's data model

TransportProvider and *Transportee* store the details of the platform's user (i.e. the trasport companies and the transportation users, respectively).

Vehicle is the entity responsible for storing the data of the companies' fleet of vehicles. It has three *VehicleTypes:* electric vehicle, internal combustion and alternative fuel.

The *Wallet* entity is associated with an owner, either a company or a user, and maintains the balance. Whenever a deposit or withdrawal occurs, the balance is updated, and simultaneously, a record of the transaction (either *Deposit* or *Withdrawal*) is stored. Similarly, when a payment is executed, the balances of both involved wallets are adjusted accordingly and recorded.

The *Ride* entity stores information about the transportation user, the vehicle used, date, starting and ending points, cost, and distance traveled. Several linked rides collectively form a *Trip* record.

4 Tests and Results

The backend of the application was functionally tested through Open API 2.2.0, that was configured for the platform's ReST API.

To assess the platform's response time variance in relation to both the number of concurrent requests and the total records stored in the blockchain, a series of load tests were conducted. It is important to highlight that the entire platform, encompassing both the backend and the blockchain network, was deployed on a single machine. Consequently, the temporal performances obtained are not absolute and are contingent on the final production deployment. These tests specifically gauge how temporal performances fluctuate based on the mentioned parameters.

The test environment was deployed on the following configuration: Intel® Core™ i7-8565U CPU @ 1.80GHz × 8, 16 GB RAM, Ubuntu 22.04.3 LTS. The tool used for conducting the load tests was Apache JMeter 5.6.2.

The tests evaluate two of the common operations that the users can access through the client applications, namely retrieving the wallet by its ID, and getting the total amount expenses per month. The state database of Fabric is CouchDB and an index was added for the second operation on its search criteria: [*sourceWalletId*, *date*].

After populating the blockchain with 10.000, 100.000 and 1.000.000 records, respectively the tests have shown that the response times don't depend on the number of records stored, if they are indexed by the search criteria. Table 1 contains the average response time of the blockchain per number of parallel requests.

Table 1. Load test results

No. of requests	Get wallet by ID time [ms]	Total cost per month time [ms]
1	6	11
10	14	28

50	67	100
100	134	158
150	205	292
200	363	403
250	399	521
300	501	633
400	713	833

It should be noted that at 400 requests in parallel the response error rate (timeout) was around 10%, on average for both operations. This number of request limit can be used as a reference for tuning the number of workers for the messaging queue.

5 Conclusions

This research explore application of blockchain technology in passenger transportation within smart cities, emphasizing its integration into a Mobility as a Service (MaaS) framework. Throughout the study, we have explored the potential of blockchain in enhancing the efficiency, security, and sustainability of urban transportation networks. Our investigation reveals that blockchain technology can effectively address the complex challenges of integrating various transportation modes and stakeholders, offering a decentralized, transparent, and secure system. Additionally, the proposed technical infrastructure based on Hyperledger Fabric has demonstrated feasibility and the capacity to handle high loads and requests, indicating its suitability for the anticipated demands of integrated transportation systems.

Key highlights of our research include the detailed analysis of blockchain's role in streamlining payment and ticketing processes, ensuring transparent and secure transactions among diverse transportation services. We have also examined the technical aspects of implementing a blockchain-enabled MaaS system using Hyperledger Fabric, including high level solution architecture and data model. Future research should focus on pilot implementations, testing, and further exploration of blockchain's capabilities to address the evolving needs of urban transportation systems. In addition, the system should be extended by integrating mechanisms to facilitate integration of passenger and freight transportation.

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