Block-CPS: Blockchain and Non-Cooperative Game-Based Data Pricing Scheme for Car Sharing

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***Abstract*—This article proposes a blockchain and non-cooperative game theoretic-based secure and optimized data pricing scheme, i.e., *Block-CPS*. It aims to secure the data transactions between vehicle owners and customers for rides. It uses the fifth-generation (5G) communication network that offers ultrareliable low-latency communications between vehicle owners and customers. The Interplanetary file system (IPFS) storage protocol used in the proposal reduces the blockchain data storage cost. We then formulated a non-cooperative game-theoretic approach to maximize the profits for vehicle owners and customers. Formulated non-cooperative game is integrated with blockchain to provide security to the *Block-CPS*. The vulnerability of the developed smart contract is verified and validated using tools like smartcheck and verisol. The performance of *Block-CPS* is evaluated by comparing it with the traditional approaches using blockchain with 4G and LTE-A networks. The performance evaluation parameters used are system scalability, network latency, data storage cost and its computation, network throughput, profit, communication reliability, and convergence for the optimal payoff between vehicle owners and customers. The performance results shows the *Block-CPS* outperforms the traditional blockchain-based systems.**

***Index Terms*—Blockchain, car sharing, data pricing, ethereum, non-cooperative game, smart contract.**

I. Introduction

In recent years, a huge amount of data has been generated as car sharing is getting more demands over personal vehicles due to the increased road traffic and travel costs [1]. Nowadays, people prefer to travel by car sharing than their cars due to minimal usage, which is approx. < 90 mins/day [2]. Car sharing offers various benefits, such as reduced air pollution, energy savings, cost savings, and minimizing road traffic, attracting travelers to prefer this mode of travel [3]. As car sharing is increasing due to the aforementioned benefits, many organizations have started developing online centralized platforms for easily finding shared rides accessible via open Internet channels. The open channel centralized platforms can come across various security and privacy issues that restrict travelers from using and benefitting from online ride sharing platforms [4].

The security and privacy of centralized ride sharing systems are vulnerable to third-party systems as they can misuse the user's confidential information and demand the drivers to pay high price [5], [6]. A decentralized and trustable system is required to mitigate the aforementioned security and privacy issues in the ride sharing system. The users and drivers can be treated fairly in the system. Users should pay fairly in the system, and keeping track of the driver's behavior toward the users is very important to make the system secure, reliable, fair, and trusted.

Many researchers across the globe have given blockchain-based decentralized ride sharing solutions to mitigate the security and privacy issues of centralized systems, such as data modification, sniffing, eavesdropping, denial of service attacks, and many more [1]. However, a few of the works are as follows: Baza *et al.* [6] proposed a decentralized B-ride system, a public blockchain-based ride sharing system to protect users against malicious attackers by implementing zero-knowledge set membership proof (ZKSM). Then, Dai *et al.* [7] discussed the integration of blockchain technology with the Internet of Things (IoT), i.e., BCoT, to resolve the interoperability and security issues in the system by providing the survey on BCoT. Later, Ferrag *et al.* [8] surveyed the blockchain-based technologies with different IoT domains, such as the Internet of Vehicles (IoV), which faces various combined attacks and security issues. Then, Pal and Ruj [9] investigated an ethereum blockchain-based solution, i.e., BlockV, to ensure data confidentiality in the ride sharing system.

Xu *et al.* [1] designed a consortium blockchain-based framework to create a P2P network enabling the data security

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for car sharing. They have used the Stackelberg game approach to evaluate the optimal pricing scheme. Later, Wang and Zhang [10] also presented a consortium blockchain-based scheme to secure ride sharing services. An attribute-based proxy reencryption algorithm has been used to make the system more transparent and secure. Huang *et al.* [11] discussed a car sharing decentralized architecture that focuses on maintaining the privacy of the customer's identity with the help of privacy-preserving identity management. To further resolve the security issues in blockchain-based IoT systems in [8], Ferrag and Shu [12] surveyed various blockchain-based systems for different types of IoT fields, such as IoV, Internet of Energy (IoE), etc., with the help of various security analysis techniques and consensus algorithms. Then, Peng *et al.* [13] provided an extensive survey to resolve security issues with smart contracts integrated with IoT for different blockchain platforms [14], [15].

All security-related solutions given by the researchers may endure various issues, such as man-in-the-middle attacks, security issues related to user's identity, communication overhead, scalability issues, less user friendly, and no anonymity. The security issues mentioned above of ride sharing systems can be resolved by incorporating blockchain technology with a non-cooperative game-theoretic approach, which is a secure and credible solution. We have formulated a non-cooperative game to satisfy the vehicle owners and customers with ride sharing data pricing. The non-cooperative game ensures that no players can cheat or conflict with each other. Furthermore, using the 5G communication network ensures the system is efficient and reliable. This article presents a blockchain and the non-cooperative game-based data pricing scheme for car sharing over the 5G network to secure data sharing among vehicle owners and customers. As a result, vehicle owners can get their ride sharing benefits, and customers do not have to pay high prices for their rides.

A. Motivation

Most of the researchers have given ride sharing schemes [11], [16], but they have not focused on the security aspects of the proposed system. They have also utilized a centralized storage and interpretation system for ride data sharing. These solutions can pose security, single point of failure, reliability, and trust issues. Later, the Baza *et al.* [6] and Dai *et al.* [7] discussed blockchain-based ride sharing solutions to offer security, reliability, and trust to vehicle owners and customers. Moreover, they have managed to achieve security, but without considering the price optimality factor that can cause severe loss to vehicle owners and customers involved in the ride sharing in case of not adequately utilized. Thus, there is a need for a system that considers an optimal data pricing scheme for both vehicle owner and customer, allowing customers to book their rides optimally with a satisfying profit.

B. Research Contributions

The research contributions of this article are as follows.

1) We propose a blockchain-based secure and efficient data pricing scheme, i.e., *Block-CPS* for car sharing over a 5G communication network.
2) An IPFS-based data storage system is introduced for *Block-CPS* to make the data transactions secure and cost-efficient.
3) We used a non-cooperative game-theoretic approach for optimal pricing (both riders and owners earns profit) between the vehicle owners and customers. Furthermore, a non-cooperative game integrated with blockchain enhances security in *Block-CPS*.
4) Finally, we evaluated the performance of *Block-CPS* by considering parameters, such as scalability, network latency, data storage cost and its computation, network throughput, profit comparison, communication reliability, and convergence for the optimal payoff between vehicle owners and customers. Results illustrated that the performance of the proposed system outperforms the traditional systems.

C. Organization

The remainder of this article is organized as follows. Section II presents the system model and problem formulation. Section III describes the proposed *Block-CPS*. Section IV presents the non-cooperative game-theoretic approach. Results and discussion is presented in Section V, and finally, this article is concluded in Section VI.

II. System Model and Problem Formulation

A. System Model

Fig. 1 shows a blockchain-based data pricing scheme, i.e., *Block-CPS* for the car sharing scheme. It consists of three entities vehicle owners (E_ϑ), registration authority (E_Λ), and customers (E_θ), which are connected via 5G communication network. Blockchain has been used to eliminate third-party systems to achieve trust and security in data sharing. If the vehicle owner and customer want to add themselves to the blockchain, they must first register with the registration authority. After registration, a smart contract has been executed to check whether the vehicle owner or a customer has a valid certificate for exchanging data transactions over the blockchain network. They can add data transactions to the blockchain network if they have a valid certificate. A non-cooperative game theory has been introduced in *Block-CPS* to achieve optimality at data prices and make the system fair. To overcome the high cost of data storage issues of ethereum blockchain, the proposed scheme uses an IPFS storage protocol using hash keys for data storage. IPFS is a decentralized, immutable, and secure storage system and is also free of cost. We preferred 5G as a communication network to enhance the network performance such as latency, reliability, and availability of the system as it provides various features, such as ultralow latency (< 1 ms), high data speed (< 10 Gb/s), and high availability ($< 99.9999\%$).

Fig. 2 shows the detailed sequence of the *Block-CPS* to get the optimal payoff for vehicle owner and customer. We have

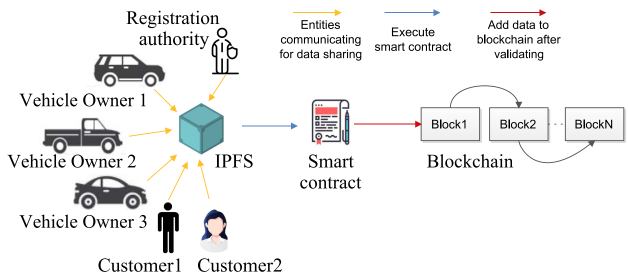


Fig. 1. *Block-CPS* system model.

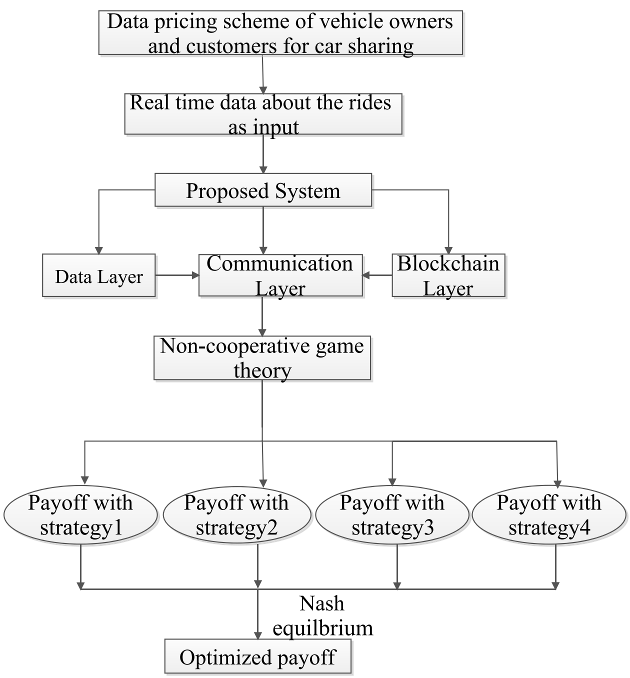


Fig. 2. Flow of the *Block-CPS*.

considered vehicle owners and customer data about the rides as input. Further, the proposed system consists of three layers, i.e., data, communication, and blockchain. The output of the data layer feeds as an input to the communication layer to further add it to the blockchain. Moreover, a non-cooperative game theory has been designed with pure strategy, which further consists of payoff for different strategies to get a maximal payoff at the Nash equilibrium.

B. Problem Formulation

We have considered the set of three entities $E \in \{E_\vartheta, E_\Lambda, E_\theta\}$, where E_θ is a set of r registration authorities $\theta_u \in \{\theta_1, \theta_2, \dots, \theta_r\}$ with which multiple customers ($\in E_\Lambda$) and vehicle owners ($\in E_\vartheta$) are associated for registration. E_ϑ is a set of v vehicle owners $\{\vartheta_1, \vartheta_2, \dots, \vartheta_v\}$, which can be associated with multiple customers $\Lambda_j \in \{\Lambda_1, \Lambda_2, \dots, \Lambda_c\}$ for ride sharing. Customers ($\in E_\Lambda$) need to be associated with any mth vehicle owner, i.e., $\vartheta_m \in E_\vartheta$ for ride in exchange of money (in ether) i.e., Ω_{Λ_j} ($\in E_\Lambda$) $\rightarrow \Omega_{\vartheta_m}$, where Ω_{Λ_j} and Ω_{ϑ_m} are ethereum wallets of the jth customer and mth vehicle owner. The relationship between all the entities is mentioned as follows:

$$\vartheta_m \xrightarrow{\epsilon} \sum_{j=1}^{s} \Lambda_j \quad \text{and} \quad \Lambda_j \xrightarrow{\epsilon} \sum_{m=1}^{t} \vartheta_m \tag{1}$$

$$\Lambda_j \xrightarrow{\epsilon} \sum_{u=1}^{s'} \theta_u \quad \text{and} \quad \vartheta_m \xrightarrow{\epsilon} \sum_{u=1}^{t'} \theta_u \tag{2}$$

$$s \leq c, \quad t \leq v, \quad s' \geq s, \quad t' \geq t \tag{3}$$

$$j \in [1, c], m \in [1, v], j, m, u \geq 0 \tag{4}$$

where ϵ signifies the communication between vehicle owner ϑ_m, customer Λ_j, and registration authority θ_u for ride sharing. t and s denote the number of vehicle owners ϑ_m and the number of customers Λ_j interacting so that customers can book the ride with the help of their wallet. $t'$and s' denote the number of vehicle owners ϑ_m and number of customers Λ_j registering to r number of registration authorities to get validated for data storage in IPFS. ϑ_m and Λ_j are connected through an IPFS network to store the customer's request or vehicle owner's statement about the data for rides for which the smart contract approves the certificate if they contain the valid certificate, i.e., φ or not. If they contain the valid certificate then smart contract can allow vehicle owner or customer's data to be stored into the IPFS and IPFS can give back the set of hash keys $\gamma_k \in \{\gamma_1, \gamma_2, \dots, \gamma_h\}$ to the vehicle owners and $\gamma_e \in \{\gamma_1, \gamma_2, \dots, \gamma_w\}$ the customers. Λ_j can check their data anytime in the IPFS by using their γ_e. The mentioned entities can be denoted as follows:

$$\vartheta_m \xrightarrow{\zeta} \sum_{k=1}^{h'} \gamma_k \quad k > 0, h' \leq h \tag{5}$$

$$\Lambda_j \xrightarrow{\zeta} \sum_{e=1}^{o} \gamma_e; \, e > 0, o \leq w \tag{6}$$

where ζ signifies h' and o number of hash keys γ_k and γ_e associated with ϑ_m and Λ_j.

Now, vehicle owners and customers have their own hash keys associated with them which the IPFS has returned after validating their certificate with a smart contract. Now, the data is to be added (vehicle owner's or customer's data about the rides) to the blockchain network. Blockchain consists of a chain of blocks linked together to store the transactions and their information and validate the new blocks. When vehicle owners or customers want to add their data to the blockchain, their hash keys should correspond to the hash of the block header in the blockchain. A block comprises of block number, nonce, timestamp, and block data to validate the vehicle owner or customer's data block. The previous hash of the block (λ^{prev}) and the block data (B^d) can be used to compute the hash of the current block header (λ^{bh}), which is elaborated as follows [17]:

$$\lambda : \sigma \rightarrow \{0, 1\}^y \quad \forall \sigma \in A_{\vartheta_m, \Lambda_j}; \lambda(\sigma) = \sigma' \tag{7}$$

$$\lambda(\sigma') \neq \sigma, \sigma_1 \neq \sigma_2, \lambda(\sigma_1) \neq \lambda(\sigma_2) \tag{8}$$

where A is the set of matrices of the vehicle owner and customer's data. σ denotes the message of original data of vehicle owner and customer.

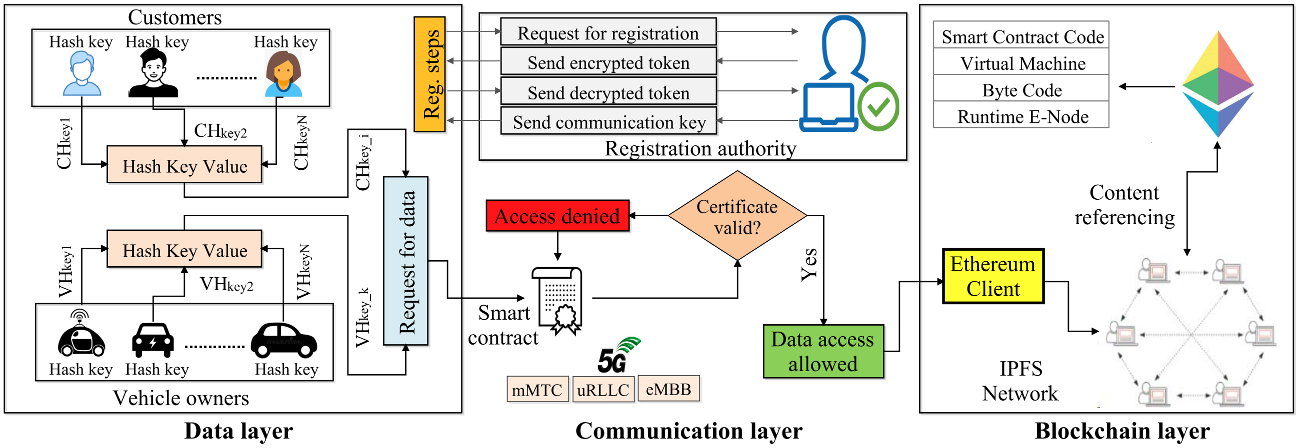


Fig. 3. Proposed *Block-CPS* framework.

The hash of block header (λ^{bh}) consists of $\{\lambda^{\text{prev}}, B^d\} \in \lambda^{bh}$. So, if a vehicle owner or customer want to add their data about the rides, their hash should correspond to the block header's hash. The mentioned entities can be shown as follows:

$$\sum_{k=1}^{h'} \gamma_k \xrightarrow{\alpha} \lambda^{bh}, k > 0, \quad k \in [1, h] \tag{9}$$

$$\sum_{e=1}^{o} \gamma_e \xrightarrow{\alpha} \lambda^{bh}; e > 0, \quad e \in [1, w] \tag{10}$$

where α signifies the particular hash keys associated with ϑ_m and Λ_j, which correlate to the block hash of blockchain.

After validating the blocks, vehicle owners have their data about the prices of car sharing stored in the blockchain. Customers can view and book their ride according to the location and price appropriately. For example, number of rides can be denoted by $\{R_1, R_2, R_3, \ldots, R_r\} \in R_z$. A vehicle owner has three available rides $\{R_1, R_2, R_3\}$ which customer can check in the blockchain to book for their visit, and if the customer finds it appropriate to book, then, the vehicle owner has left two available rides $\{R_1, R_2\}$ for booking. When the vehicle owner has no available ride to broadcast, then, the customer has to look for the other rides available. Entities vehicle owner and customer are connected with each other and can interact with the help of their Ω_{ϑ_m} and Ω_{Λ_j} addresses which can be represented as follows [18]:

$$\Omega_{\vartheta_m} = \left\{\delta^{\vartheta_m}, \Delta^{\vartheta_m}, \vartheta_m^{\mu}, \phi_{\vartheta_m}, \eta, T_{\text{merkle}}\right\} \tag{11}$$

$$\Omega_{\Lambda_j} = \left\{\delta^{\Lambda_j}, \Delta^{\Lambda_j}, \Lambda_j^{\mu}, \phi_{\Lambda_j}, \eta, T_{\text{merkle}}\right\} \tag{12}$$

where δ^{ϑ_m} and δ^{Λ_j} denote the private key and Δ^{ϑ_m} and Δ^{Λ_j} denote the public key for ϑ_m and Λ_j. Hash can be expressed with the help of ϑ_m^{μ} and Λ_j^{μ} and ϕ_{ϑ_m} and ϕ_{Λ_j} signify the timestamp required for ϑ_m and Λ_j. η denotes the gas required for a transaction and T_{merkle} denotes the Merkle tree.

Entities can interact with each other over the 5G network as we need a car sharing scheme that should satisfy the customer's experience of ride so using a 5G network provides a fast and reliable service with its characteristics for the customer's ride, which are follows:

$$\text{Avail}_{5G} \approx 99.999\%, \tag{13}$$

$$DR_{5G} \leq 10 \text{ Gb/s} \quad \text{and} \quad L_{E2E} < 1 \text{ ms} \tag{14}$$

where Avail_{5G}, DR_{5G}, and L_{E2E} denote the high availability, high data rate, and ultralow latency associated with the 5G network. 5G offers entities to communicate efficiently with each other for ride sharing with minimum delay (i.e., < 1 ms) as per the customer and vehicle owner satisfaction.

III. *Block-CPS*: The Proposed Scheme

This section presents the proposed blockchain-based data pricing scheme for car sharing. A non-cooperative game has been formulated for the same and the proposed framework is implemented over the 5G network to make the system reliable and secure. Fig. 3 presents the *Block-CPS* framework in detail. The proposed framework aims to enhance the communication security between vehicle owners and customers. The proposed architecture is divided into three layers: 1) data layer; 2) communication layer; and 3) blockchain layer. These three layers with their functions are explained in detail as follows.

A. Data Layer

Data Layer is the primary layer of *Block-CPS*, where entities can communicate with each other. Entities involved in the communication are vehicle owners and customers associated with their hash keys. In a ride sharing system, customers want to book their ride according to their visit, and vehicle owners will provide details about the number of available rides with their assigned prices in the system. Therefore, customers and vehicle owners need to store their information on the ride sharing like vehicle owners will broadcast the available rides with their prices. In addition, customers need to store details about the destination of their visit and their willing price. So, in the data layer, vehicle owners and customers request their data about the rides to be stored in IPFS, which has to go through the communication layer to satisfy some conditions checked by the registration authority.

Fig. 3 shows the registration steps the vehicle owners and customers must follow before storing the data. The registration authority will authorize vehicle owners and customers by sending them an encrypted token to show while keeping the data in IPFS. The proposed scheme ensures that communication between the entities and their data should be secured, trusted, and reliable.

B. Communication Layer

The communication layer is the one through which all data transmissions can perform securely over the 5G communication network. The 5G communication network used in the proposed scheme ensures fast and reliable data transmission with its multiple features, such as high resolution and high data rate, facilitating the massive amount of data transmission [19]. In this layer, the smart contract authorizes the vehicle owner's and customer's authorization in the network after registering with the registration authority. Vehicle owners and customers have their hash keys associated with them; smart contracts authorize the certificate of vehicle owners or customers to check whether they are trusted users. If they are authorized, they can store their data successfully. But, they will be denied storing it if they do not have a valid certificate. So, all data transmission will be securely performed in the communication layer over the 5G network.

C. Blockchain Layer

All the transmission of data about the rides has been through the communication layer to verify the authorization of vehicle owners and customers by executing the smart contract to check their authorization for storing the data in IPFS. Data storage in IPFS is free of cost and ensures the availability and reliability of data in a car sharing system. IPFS can store the data of vehicle owners and customers data after validating with a smart contract in the following form [20]:

$$\text{ipfs.files.add}\left\{A_{\vartheta_m, \Lambda_j}\right\} \tag{15}$$

where A denotes the set of matrices associated with data of ϑ_m and θ_u. The blockchain layer mainly focuses on storing data in IPFS, which will then be added to the blockchain so that the customers can check the details about the rides broadcasted by vehicle owners. Algorithm 1 demonstrates the detailed procedure of storing the data in IPFS as requested by vehicle owners and customers. Vehicle owners and customers can request to add their data about the rides in the blockchain. In the algorithm, after executing the smart contract to validate the certificate of the vehicle owner or customer, IPFS will return the hash keys to the vehicle owner and customer. If their hash keys correspond to the hash of the blockchain (λ^{bh}), then, they can add their data to the blockchain successfully with the time complexity of O(v) and O(c); otherwise, access will be denied.

Fig. 4 also presents a blockchain-based handshake diagram in which vehicle owners or customers send a request to add data to the blockchain. Before that, they have to register themselves to the registration authority for the certificate; IPFS will facilitate the hash keys to the authorized vehicle owners or customers after validating the certificate. After validating the certificate, vehicle owners or customers can add their data to the blockchain. For that, their hashes should be as per the hash of the blockchain.

Algorithm 1 Blockchain-Based Data Storage Algorithm

Input: IPFS(hash,key), γ_k, γ_e, A_{ϑ_m}, A_{Λ_j},φ, λ^{bh}
Output: Add A_{ϑ_m} and A_{Λ_j} to the blockchain

procedure BLOCKCHAIN_STORAGE(ϑ_m, Λ_j, γ_k, γ_e,RA)
  if $E \in E_{\vartheta_m}$ **then**
    for $i = 1, 2, \ldots, v$ **do**
      IPFS($hash, key$) $\leftarrow$Request_to_datastore(ϑ_m)
      $\vartheta_m \xleftarrow{token} \theta_u$
      Execute smart contract
      if $\vartheta_m \in \varphi$ **then**
        IPFS($hash, key$) $\leftarrow A_{\vartheta_m}$
        $\gamma_k \leftarrow IPFS(hash, key)$
        $blockchain$ $\leftarrow$ Request_to_add (A_{ϑ_m})
        if $\gamma_k \in \lambda^{bh}$ **then**
          Data added successfully
        else
          Access denied
        end if
      else
        Invalid Certificate
      end if
    end for
  else if $E \in E_{\Theta_j}$ **then**
    for $i = 1, 2, \ldots, c$ **do**
      IPFS($hash, key$) $\leftarrow$Request_to_datastore(Λ_j)
      $\Lambda_j \xleftarrow{token} \theta_u$
      Execute smart contract
      if $\Lambda_j \in \varphi$ **then**
        IPFS($hash, key$) $\leftarrow A_{\Lambda_j}$
        $\gamma_e \leftarrow IPFS(hash, key)$
        $blockchain$ $\leftarrow$ Request_to_add (A_{Λ_j})
        if $\gamma_e \in \lambda^{bh}$ **then**
          Data added successfully
        else
          Access denied
        end if
      else
        Invalid Certificate
      end if
    end for
  end if
end procedure

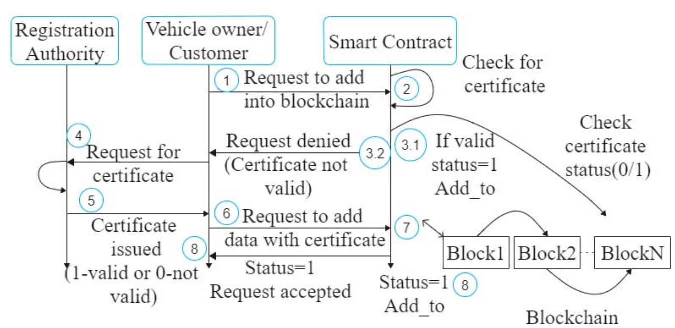


Fig. 4. *Block-CPS* handshake diagram.

IV. Non-Cooperative Game Approach

A non-cooperative game has been formulated for a blockchain-based data pricing scheme for car sharing, which comprises vehicle owners and customers who will follow the pure strategy in the game. It means players make their strategies individually and do not communicate with each other [21]. But both players, vehicle owner, and customer, will try to maximize the profit for the rides leading to a situation where we need to discuss the data pricing for rides between entities, vehicle owners, and customers. Therefore, we will analyze the non-cooperative game to examine the data pricing for entity customers and vehicle owners.

The game consists of two players vehicle owners ϑ_m and customers Λ_j who can check the available rides $\{R_1, R_2, R_3, \ldots, R_r\} \in R_z$ with its associated prices $\{P_{R_1}, P_{R_2}, \ldots, P_{R_r}\}$ assigned by vehicle owners using GPS in the blockchain. Let $S_{\vartheta_m} = \{S_1, S_2\}$ be the pure strategy of vehicle owners, which are route selection and maximum price for the ride, it means vehicle owners can maximize their profit if the available ride takes the long route. They can maximize the ride price if there is a maximum number of shares in the car. Let $S_{\Lambda_j} = \{S_1, S_2\}$ be the strategy of customers which are route selection and minimum price to travel, it means customers prefer the ride to take short route so that they have to pay less price. They want the minimum number of shares in the ride with the minimum price to take less time to reach their destination. Vehicle owners and customers both will try to maximize their payoff, which we can define in terms of the utility function, i.e., $X_{(\vartheta_m,\Lambda_j)}(S_{\vartheta_m}, S_{\Lambda_j})$ according to their strategies. Now we can consider the utility function in the form of a matrix and discuss it.

In the utility matrix, $X_{(\vartheta_m,\Lambda_j)}$ as a payoff can be calculated based on the strategies $S_{\Lambda_j} = \{S_1, S_2\}$ for vehicle owners and $S_{\Lambda_j} = \{S_1, S_2\}$ for customers. Therefore, we can express payoff matrix considering the strategies for vehicle owner and customer, which is defined as follows:

$$X_{(\vartheta_m,\Lambda_j)} = \begin{bmatrix} \left(S_{1_{\vartheta_m}}, S_{1_{\Lambda_j}}\right)\left(S_{1_{\vartheta_m}}, S_{2_{\Lambda_j}}\right) \\ \left(S_{2_{\vartheta_m}}, S_{1_{\Lambda_j}}\right)\left(S_{2_{\vartheta_m}}, S_{2_{\Lambda_j}}\right) \end{bmatrix}. \tag{16}$$

Now, we can evaluate payoff $X_{(\vartheta_m,\Lambda_j)}$ for vehicle owner and customer with strategies in which vehicle owner want the ride to take the long route to maximize their price for ride and customers want to travel through the shortest route so that they have to pay a lesser price. The number of d routes for rides is denoted by $\{\rho_1, \rho_2, \ldots, \rho_d\} \in \rho_p$. The payoff $X_{(\vartheta_m,\Lambda_j)}$ of vehicle owner and customer with strategy $\{S_{1_{\vartheta_m}}, S_{1_{\Lambda_j}}\}$ is represented as follows:

$$X_{(\vartheta_m,\Lambda_j)} = \left\{S_{1_{\vartheta_m}}, S_{1_{\Lambda_j}}\right\} \tag{17}$$

$$S_{1_{\vartheta_m}} \xrightarrow{\iota} \max \sum_{p=1}^{d'} \rho_p;\ d' \le d, p > 0 \tag{18}$$

$$S_{1_{\Lambda_j}} \xrightarrow{\iota} \min \sum_{p=1}^{d'} \rho_p;\ d' \le d, p > 0 \tag{19}$$

where ι signifies the strategy of ϑ_m and Λ_j based on the d' number of routes for ride sharing, and here, vehicle owner and customer can select different types of routes, i.e., short route and long route according to their benefit. In the utility matrix, $X_{(\vartheta_m,\Lambda_j)}$ defines the payoff of the vehicle owner and customer with strategies in which vehicle owners want to ride to take the long route to their benefits, and customers want to travel at a minimum price. The payoff $X_{(\vartheta_m,\Lambda_j)}$ of vehicle owner and customer with strategy $\{S_{1_{\vartheta_m}}, S_{2_{\Lambda_j}}\}$, is represented as follows:

$$X_{(\vartheta_m,\Lambda_j)} = \left\{S_{1_{\vartheta_m}}, S_{2_{\Lambda_j}}\right\} \tag{20}$$

$$S_{1_{\vartheta_m}} \xrightarrow{\iota} \max \sum_{p=1}^{d'} \rho_p;\ d' \le d, p > 0 \tag{21}$$

$$S_{2_{\Lambda_j}} \xrightarrow{\pi} \min \sum_{q=1}^{r'} P_{R_q};\ r' \le r, q > 0 \tag{22}$$

where ι and π denote the strategy of vehicle owners and customers based on the d' number of routes and r' number of prices assigned to the rides.

In the utility matrix, $X_{(\vartheta_m,\Lambda_j)}$ denotes the payoff of the vehicle owner and customer with strategies in which vehicle owners want to gain maximum price from customers to maximize their profit and customers want to travel through the shortest route (minimize) so that they have to pay a lesser price. The payoff $X_{(\vartheta_m,\Lambda_j)}$ of vehicle owner and customer with strategy $\{S_{2_{\vartheta_m}}, S_{1_{\Lambda_j}}\}$ is represented as follows:

$$X_{(\vartheta_m,\Lambda_j)} = \left\{S_{2_{\vartheta_m}}, S_{1_{\Lambda_j}}\right\} \tag{23}$$

$$S_{2_{\vartheta_m}} \xrightarrow{\xi} \max \sum_{q=1}^{r'} P_{R_q};\ r' \le r, q > 0 \tag{24}$$

$$S_{1_{\Lambda_j}} \xrightarrow{\iota} \min \sum_{p=1}^{d'} \rho_p;\ d' \le d, p > 0 \tag{25}$$

where ξ and ι signify the strategy of vehicle owners and customers based on the r' number of assigned prices and d' signifies number of routes for ride sharing. In the utility matrix, $X_{(\vartheta_m,\Lambda_j)}$ is considered as the payoff of the vehicle owner and customer with strategies in which vehicle owners want to gain the maximum price from the customers for the ride and customers want to travel so that they have to pay the minimum price for the ride. The payoff $X_{(\vartheta_m,\Lambda_j)}$ of vehicle owner and customer with strategy $\{S_{2_{\vartheta_m}}, S_{2_{\Lambda_j}}\}$, is represented as follows:

$$X_{(\vartheta_m,\Lambda_j)} = \left\{S_{2_{\vartheta_m}}, S_{2_{\Lambda_j}}\right\} \tag{26}$$

$$S_{2_{\vartheta_m}} \xrightarrow{\xi} \max \sum_{q=1}^{r'} P_{R_q};\ r' \le r, q > 0 \tag{27}$$

$$S_{2_{\Lambda_j}} \xrightarrow{\pi} \min \sum_{q=1}^{r'} P_{R_q};\ r' \le r, q > 0. \tag{28}$$

Now, we have discussed all the possible strategies and the associated payoff that vehicle owners and customers can adapt in a non-cooperative game through the utility matrix. In a non-cooperative game, Nash equilibrium is a stable condition after which players cannot deviate from their strategy after going through another player's strategy to gain payoff [22]. In this situation, vehicle owners want that ride to take a long route, and the price should be maximum, and customers want to travel through a short route and pay the minimum price. Still, it is not always possible to be conditions in their favor when we talk about ride sharing. So, there is a need for a condition that can satisfy both vehicle owners and customers in terms of profit. For that, a Nash equilibrium exists between the vehicle owner and customer with the utility matrix $X_{(\vartheta_m,\Lambda_j)}$ considering the strategy $\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\}$, i.e., route selection lies in between short route and long route and price can be finalized between minimum price and maximum price so that both vehicle owners and customers can be satisfied. The payoff $X^N_{(\vartheta_m,\Lambda_j)}$ of the vehicle owner and customer at a Nash equilibrium with strategy $\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\}$ is represented as follows:

$$X^N_{(\vartheta_m,\Lambda_j)} = \left\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\right\} \tag{29}$$

$$\min\sum_{p=1}^{d'} \rho_p < S^*_{\vartheta_m} < \max\sum_{p=1}^{d'} \rho_p \tag{30}$$

$$\min\sum_{q=1}^{r'} P_{R_q} < S^*_{\Lambda_j} < \max\sum_{q=1}^{r'} P_{R_q} \tag{31}$$

where $S^*_{\vartheta_m}$ and $S^*_{\Lambda_j}$ denote the strategy of vehicle owner and customer with the existence of Nash equilibrium using the applied non-cooperative game theory approach. r' and d' signify the number of assigned prices and routes for the rides, which lie between minimum and maximum so that both vehicle owner and customer can get benefit equally.

Definition 1: Nash Equilibrium: The non-cooperative game theory consists of different pair of pure strategies $\{S_{1_{\vartheta_m}}, S_{1_{\Lambda_j}}\}$, $\{S_{1_{\vartheta_m}}, S_{2_{\Lambda_j}}\}$, $\{S_{2_{\vartheta_m}}, S_{1_{\Lambda_j}}\}$, and $\{S_{2_{\vartheta_m}}, S_{2_{\Lambda_j}}\}$ in which players vehicle owner and customer attempt to maximize their payoff in the ride sharing system. It leads to the existence of Nash equilibrium with the strategy $S^*_{\vartheta_m}$ and $S^*_{\Lambda_j}$ after which player cannot diverge from this strategy to gain more payoff than other players [23].

Theorem 1: The non-cooperative game theory is applied to obtain the optimal payoff between vehicle owners and customers along with the strategy $\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\}$ satisfies the uniqueness property of the existence Nash Equilibrium.

Proof: The non-cooperative game theory along with the pure strategies of vehicle owners and customers fulfills the existence of an optimal payoff at a Nash Equilibrium with the strategy, i.e., $\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\}$. The criteria of uniqueness of the Nash Equilibrium is defined in the form of a standard function, i.e., best utility between users. The best utility, i.e., $X^N_{(\vartheta_m,\Lambda_j)}$ at a Nash Equilibrium is denoted by a standard function if it fulfills the following characteristics, such as positivity (Γ) and monotonicity (ψ) that can be expressed as follows [24]:

$$\Gamma = X^N_{(\vartheta_m,\Lambda_j)}\left(\{S_{\vartheta_m}, S_{\Lambda_j}\}\right), \Gamma > 0 \tag{32}$$

$$\begin{aligned}\psi &= \{S_{\vartheta_m}, S_{\Lambda_j}\} \geq \left\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\right\}\\ &\implies X^N_{(\vartheta_m,\Lambda_j)}\left(\{S_{\vartheta_m}, S_{\Lambda_j}\}\right) \geq X^N_{(\vartheta_m,\Lambda_j)}\left(\left\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\right\}\right).\end{aligned} \tag{33}$$

■

Thus, the optimal payoff achieved between vehicle owner and customer attains a unique Nash Equilibrium using pure strategy between users so that individuals do not interfere with each other while deciding the strategy to obtain the optimal payoff for their benefit.

Algorithm 2 Non-Cooperative Game for Optimal Pricing

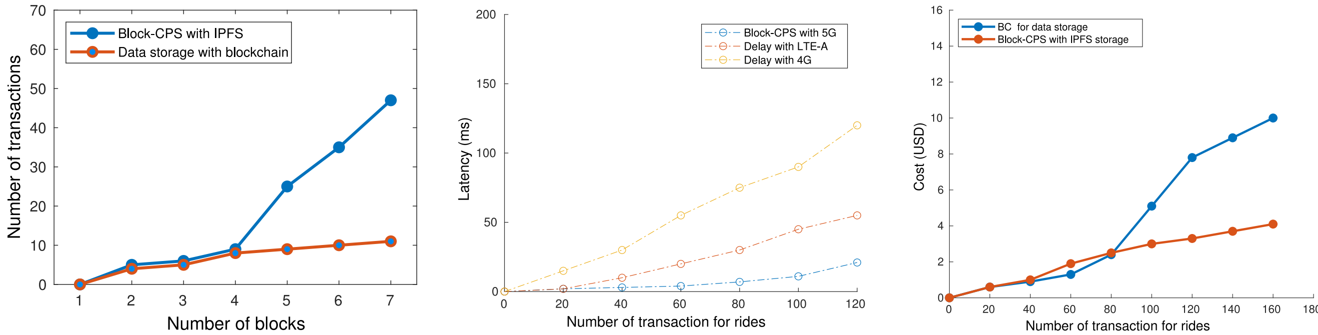
Input: γ_k, γ_e, S_{ϑ_m},S_{Λ_j}
Output: $S^*_{\vartheta_m}$, $S^*_{\Lambda_j}$
Initialization: p=1, q=1

procedure OPTIMAL_PRICE($X_{(\vartheta_m,\Lambda_j)}$, S_{ϑ_m}, S_{Λ_j}, γ_k, γ_e)
  $\{S_{\vartheta_m}, S_{\Lambda_j}\}$ = Blockchain_storage$\{\vartheta_m, \Lambda_j, \gamma_k, \gamma_e$,RA $\}$
  for each player $\{\vartheta_m, \Lambda_j\}$ with strategy S_{ϑ_m}, S_{Λ_j} **do**
    if S_{ϑ_m}, $S_{\Lambda_j} == (S_{1_{\vartheta_m}}, S_{1_{\Lambda_j}})$ **then**
      $X_{(\vartheta_m,\Lambda_j)} = \{S_{1_{\vartheta_m}}, S_{1_{\Lambda_j}}\}$
      $S_{1_{\vartheta_m}} \xrightarrow{\xi} max\sum_{p=1}^{d'} \rho_p$
      $S_{1_{\Lambda_j}} \xrightarrow{\pi} min\sum_{p=1}^{d'} \rho_p$
    else if S_{ϑ_m}, $S_{\Lambda_j} == (S_{1_{\vartheta_m}}, S_{2_{\Lambda_j}})$ **then**
      $X_{(\vartheta_m,\Lambda_j)} = \{S_{1_{\vartheta_m}}, S_{2_{\Lambda_j}}\}$
      $S_{1_{\vartheta_m}} \xrightarrow{\xi} max\sum_{p=1}^{d'} \rho_p$
      $S_{2_{\Lambda_j}} \xrightarrow{\pi} min\sum_{q=1}^{r'} P_{R_q}$
    else if S_{ϑ_m}, $S_{\Lambda_j} == (S_{2_{\vartheta_m}}, S_{1_{\Lambda_j}})$ **then**
      $X_{(\vartheta_m,\Lambda_j)} = \{S_{2_{\vartheta_m}}, S_{1_{\Lambda_j}}\}$
      $S_{2_{\vartheta_m}} \xrightarrow{\xi} max\sum_{q=1}^{r'} P_{R_q}$
      $S_{1_{\Lambda_j}} \xrightarrow{\pi} min\sum_{p=1}^{d'} \rho_p$
    else
      $X_{(\vartheta_m,\Lambda_j)} = \{S_{2_{\vartheta_m}}, S_{2_{\Lambda_j}}\}$
      $S_{2_{\vartheta_m}} \xrightarrow{\xi} max\sum_{q=1}^{r'} P_{R_q}$
      $S_{2_{\Lambda_j}} \xrightarrow{\pi} min\sum_{q=1}^{r'} P_{R_q}$
    end if
  end for
  for each $\{\vartheta_m, \Lambda_j\}$ with strategy $S^*_{\vartheta_m}$, $S^*_{\Lambda_j}$ **do**
    $X^N_{(\vartheta_m,\Lambda_j)} = \{S^*_{\vartheta_m}, S^*_{\Lambda_j}\}$
    $min\sum_{p=1}^{d'} \rho_p < S^*_{\vartheta_m} < max\sum_{p=1}^{d'} \rho_p$
    $min\sum_{q=1}^{r'} P_{R_q} < S^*_{\Lambda_j} < max\sum_{q=1}^{r'} P_{R_q}$
  end for
  Each player ϑ_m, Λ_j can communicate new strategy $\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\}$ to blockchain
end procedure

We have discussed the existence of Nash equilibrium with strategy $\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\}$, which optimizes the payoff $X^N_{(\vartheta_m,\Lambda_j)}$ for vehicle owner and customer based on the pure strategy in the non-cooperative game theory approach. But, if there is an intruder or malicious attacker trying to modify the data in ride sharing. For example, if a customer tries to book the ride with minimum price frequently, it can be a loss for the vehicle owner and lessen the chances of booking rides for another customer. Similarly, the vehicle owner can attempt to charge high prices for booking, which can also cause loss to the customers. Therefore, to mitigate these security issues, we have used a non-cooperative game theory with pure strategy in which if any malicious attacker intrude in the ride sharing system, then instead of payoff, they can be charged with a penalty (κ_{ϑ_m}) and (κ_{Λ_j}) while booking the ride. So, during the execution of the smart contract for the authenticity of users, it can declare them invalid users and discard them with a chargeable penalty.

A. Algorithm for Optimal Pricing

Algorithm 2 demonstrates the detailed procedure for an optimal pricing in the car sharing system using a non-cooperative game. The detailed procedure for optimal pricing using a non-cooperative approach consists of players, vehicle



(a) (b) (c)

Fig. 5. Performance comparison of *Block-CPS* with the traditional schemes. (a) Scalability comparison in *Block-CPS*. (b) Latency comparison in *Block-CPS*. (c) Cost comparison in *Block-CPS*.

owners who want to maximize the price for rides for their benefits, and customers who want to pay the minimum price for their visit using their strategies $\{S_{\vartheta_m}, S_{\Lambda_j}\}$. However, before discussing the non-cooperative-based algorithm of optimal pricing for vehicle owners and customers, we need to focus on the blockchain-based secure data storage, i.e., price and distance associated with the rides being used to formulate the strategies for the users. As a result, the secure data obtained from Algorithm 1 can be forwarded to formulate strategies for the vehicle owners and customers based on the different scenarios to optimize the payoff using a non-cooperative game theory approach.

So, in the algorithm, we have achieved a nash equilibrium in which both vehicle owners and customers can be satisfied by attaining a new strategy $\{S^*_{\vartheta_m}, S^*_{\Lambda_j}\}$. Considering the new strategy, the price for rides and routes both will lie between the maximum and minimum so that both vehicle owners $\{\vartheta_1, \vartheta_2, \ldots, \vartheta_v\} \in \vartheta_m$ with their time complexity of O(v) and customers $\Lambda_j \in \{\Lambda_1, \Lambda_2, \ldots, \Lambda_c\}$ with their time complexity of O(c) can be satisfied.

V. Results and Discussion

In this section, the performance of *Block-CPS* has been evaluated based on scalability, throughput, latency, the cost for data storage and its computation, profit comparison, and reliability of the system. These parameters are analyzed by deploying the smart contract of the ethereum Blockchain-based proposed system using solidity language in the remix integrated development environment (IDE) that also specifies the functionalities involved to formulate the different scenarios for the non-cooperative game theory approach. The scenarios are formulated considering the utility matrix, which consists of four different strategies based on the price and distance associated with the number of rides for vehicle owners and customers. Moreover, we have also presented the implementation interface of the proposed system using remix IDE to highlight the associated functionalities to achieve the optimal payoff for users. The detailed evaluation is as follows.

A. Scalability

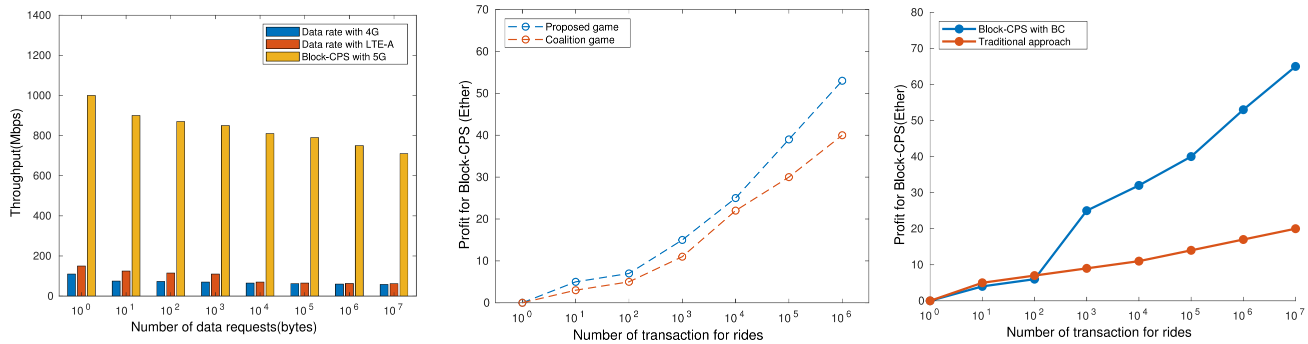
Fig. 5(a) shows the comparison of scalability of *Block-CPS* (car sharing system) with the IPFS and without IPFS storage. The *Block-CPS* scalability is higher with IPFS as it stores data free of cost and returns hash value for future access of data, but the whole block of data is stored in blockchain. So, the graph shows that initially, when the number of data blocks for storage is lesser, the system's scalability using blockchain as data storage and IPFS as data storage do not differ from each other at an extreme level. But, as the number of blocks needed to store increases, IPFS improves the scalability of the Block-CPS compared to the blockchain data storage due to its benefit to store a huge number of transactions as IPFS can store a huge amount of data in the form of hashes improving its scalability. In contrast, blockchain needs to store a whole block of data.

B. Latency

The E2E latency of the *Block-CPS* can be defined as how the *Block-CPS* is reacting with the increase in the number of transactions for rides. Fig. 5(b) presents the comparison of latency of *Block-CPS* based on various communication networks, such as 5G, 4G, and LTE-A technologies. The graph distinguishes that the 5G communication network latency is relatively low compared to 4G and LTE-A. Because of its various characteristics, such as high resolution, a high data rate lead to an end-to-end latency of less than 5 ms, i.e., Latency_E2E $<$ 1 ms. The graph depicts that latency of Block-CPS with 5G is quite low as compared to the latency of less than 20 ms, i.e., Latency_LTE-A $<$ 20 ms with LTE-A and latency of less than 50 ms, i.e., Latency_4G $<$ 50ms with 4G with the increase in the number of transaction for rides [25].

C. Cost for Data Storage

Fig. 5(c) shows the comparison of cost of *Block-CPS* for data storage based on IPFS data storage and blockchain data storage. The graph depicts that cost of the *Block-CPS* using IPFS data storage is quite low compared to blockchain data storage. Initially, when there are fewer transactions for rides, both IPFS data storage and blockchain data storage would lie at the same level. But, as the number of rides increases, storing the data in IPFS for the *Block-CPS* is quite improved and better than blockchain data storage. Because first, IPFS stores data in the form of hashes, which will lead to a lesser cost than blockchain data storage, which stores the whole block of data



(a) (b) (c)

Fig. 6. Comparison of *Block-CPS* with traditional approaches. (a) Throughput comparison in *Block-CPS*. (b) Profit analysis in *Block-CPS*. (c) Reliability comparison in *Block-CPS*.

that is quite costly. Furthermore, the cost computation parameter can be used to highlight the advantage of the introduced IPFS protocol with the blockchain network that outperforms the blockchain in terms of data storage cost.

1) Computation Cost: The computation for data storage cost can be performed to highlight the benefit of the IPFS P2P network than usage of blockchain in the proposed system. The combinatorial framework of blockchain and IPFS allows secure and efficient transactions between vehicle owners and customers for ride sharing. Foremost, gas computation is required to determine 1 kB of data storage denoted by Gt^{KB}. However, before that, gas price of a single word Gt^{Sw} of 256 bits needs to be computed to further utilize it for gas computation of 1 kB of data. The above-mentioned associations are represented as follows:

$$1Gt_{Sw} = 20 * 10^3 \text{ Gas}\left(G^s = 20k\right) \tag{34}$$

$$Gt_{KB} = \left(2^{10}/256\right) * \left(2 * 10^4\right) \text{ Gas}. \tag{35}$$

After calculating the gas for 1 kB of data, we need to consider data storage of W number of words, that can be enumerated with the help of ethereum price Em^{pe} and gas price Ga^{pe}. Therefore, the required cost for data storage (C_W^{ds}) of W number of words with the help of price of 1 ether, i.e., $1Em = 10^9$ can be expressed as follows:

$$C_W^{\text{ds}} = \left(w * G^s\right)/Em. \tag{36}$$

Thus, we can use aforementioned parameters, i.e., C_W^{ds}, Em^{pe}, and Ga^{pe} to evaluate the data storage cost of W words in U.S. Dollar, which is mentioned as follows:

$$C_{W_{\text{USD}}}^{\text{ds}} = \left(Ga^{pe} * C_W^{\text{ds}}\right) * Em^{pe}. \tag{37}$$

Therefore, to improve the performance of blockchain-based proposed system in terms of cost-efficiency, IPFS has been introduced that overcome the high storage cost issues of blockchain due to its principle of storing the data in the form a hash [26].

D. Throughput

Fig. 6(a) presents the comparison of throughput of *Block-CPS* with the different communication networks such as 4G, 5G, and LTE-A. Throughput of the network can be defined as the data rate at which the system will respond differently according to the used communication network with the increase in the number of requests for rides. It can be depicted from the graph that throughput of *Block-CPS* is less than 10 Gb/s i.e., $\text{Data\_rate}_{5G} < 10$ Gb/s with 5G is quite high as compare to the throughput of 4G which is $\text{Data\_rate}_{4G} < 100$ Mb/s and throughput of LTE-A which is $\text{Data\_rate}_{LTE-A} < 500$ Mb/s with the increase in number of requests for rides [25].

E. Profit Comparison

Fig. 6(b) shows the profit comparison for *Block-CPS* with the increase in the number of requests for rides using a non-cooperative game theory approach. Furthermore, we have implemented the proposed model of data pricing between vehicle owner and customer with the coalition game theory approach to prove enhanced optimality of the proposed non-cooperative game theory. The graph depicts the improved optimal payoff of the proposed non-cooperative game theory approach than the traditional coalition game theory. As, coalition game theory implemented between users works on the principle that players, i.e., vehicle owner and customer have to form a coalition in such a way that they have information about the other user's strategy and optimal payoff is obtained based on the defined preference order of the existent Nash Equilibrium. It means user who does not follow the preference order to surpass the other user in terms of payoff can reduce the overall payoff of the proposed model. On the other hand, the non-cooperative game theory applied in the proposed model allows players to decide their own strategy without any interference with each other. Moreover, the existence of a unique Nash Equilibrium ensures the optimal and enhanced payoff than the coalition game theory. It can be observed from the graph that when there are less number of requests for rides initially, profit for *Block-CPS* increases linearly in case of the non-cooperative game theory. But, as the number of requests increases, profit increases exponentially as we are using a non-cooperative game-theoretic approach. Thus, the improved payoff is being attained with the proposed non-cooperative game theory of unique Nash Equilibrium than the coalition game theory due to the factor of preference order.

Fig. 7 depicts the convergence feature of *Block-CPS* applied using the non-cooperative game theory. It shows that after a

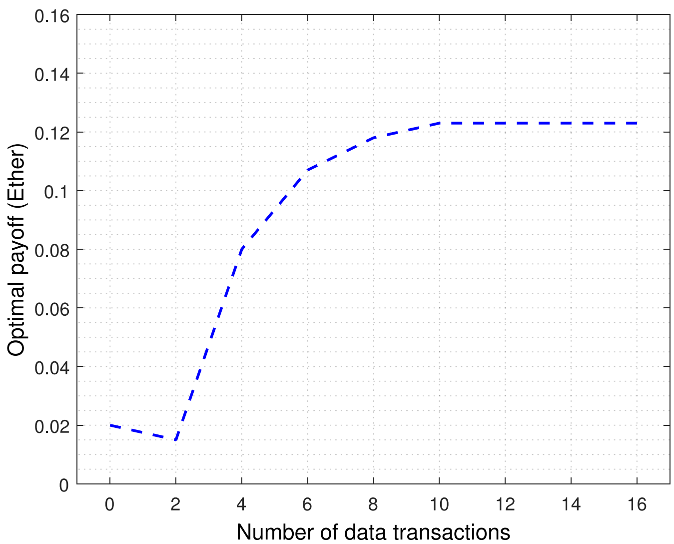


Fig. 7. Convergence.

particular point in the graph, the payoff for vehicle owner and customer remains stable. That point is called Nash equilibrium considering the pure strategy.

F. Reliability

Reliability measures how the system performs with the increase in the number of requests for rides using the blockchain approach and traditional approach. Fig. 6(c) distinguish that the proposed system with a blockchain-based approach is more reliable as compared to the traditional approach with a third-party system. Initially, when the number of requests is less for rides, the blockchain-based and traditional approaches would lie at approximately the same level. But as the number of requests increases, the reliability of the traditional approach would deteriorate as any third-party system can make it less secure by manipulating with data. But, when we compare it to the *Block-CPS*, it will be more secure and confidential to make the overall system reliability.

G. Proposed System Implementation Interface

Fig. 8 presents a detailed structure of the deployed smart contract of the proposed non-cooperative game theory approach in remix IDE for achieving the optimal payoff between vehicle owner and customer [27]. Moreover, it shows the associated functions of the smart contract, i.e., for blockchain-based secure data storage and to implement the non-cooperative game theory approach between users.

H. Security Verification of Block-CPS

In this section, we have performed security verification of the *Block-CPS* to show the secure deployment of the smart contract using various security analysis tools, such as smartcheck and verisol, which are explained as follows.

1) Smartcheck Security Analysis: First, the security analysis of *Block-CPS* has been performed over the smartcheck tool. After generating the solidity source code from ethereum, we have considered the smartcheck tool to validate the various

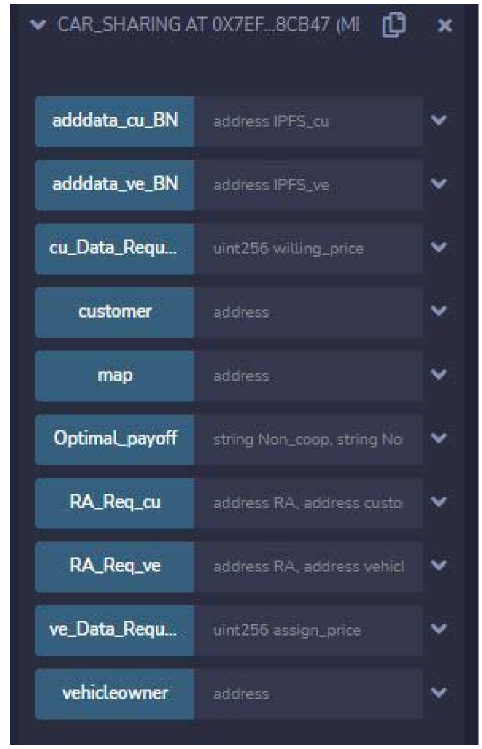
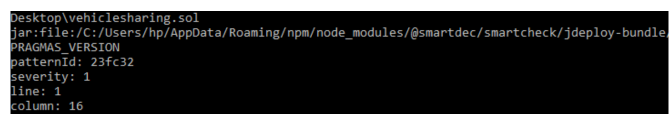
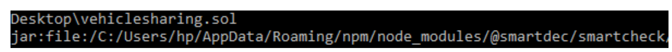


Fig. 8. Proposed system implementation interface using remix IDE.



(a)



(b)

Fig. 9. Security analysis of *Block-CPS* over smartcheck tool. (a) Security analysis over smartcheck (by default). (b) Security analysis over smartcheck.

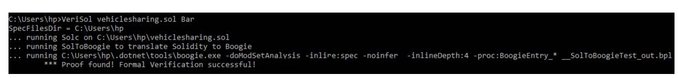


Fig. 10. Security analysis over Verisol.

vulnerabilities generated in the *Block-CPS*. Fig. 9(a) depicts that by default, the system will give one severity for a line in the source code when implemented over the smartcheck tool [28]. But, Fig. 9(b) depicts that, when we have removed the severity from that one line from the source code, it is not showing any severity or vulnerability contributing to making the *Block-CPS* secure against any vulnerability.

2) Verisol Security Analysis: We have also considered one more security analysis tool, i.e., verisol to check the existence of any vulnerability in the deployed smart contract of *Block-CPS*. Additionally, it performs the formal verification of the proposed system by generating an intermediate Boogie program considering the smart contract code as an input [29]. Fig. 10 shows that formal security verification of the smart contract over verisol highlights the successful security analysis of *Block-CPS* without any vulnerability.

VI. Conclusion

This article proposes a blockchain-based secure data pricing scheme, i.e., *Block-CPS* using IPFS data storage over the 5G communication network. It eradicates the need for third-party systems by facilitating a secure, trusted, and reliable system. We have analyzed the traditional approaches for car sharing to understand their security, the cost for data storage, latency, throughput, scalability, and reliability issues in detail. We have discussed that using IPFS in the blockchain-based data pricing scheme for car sharing over the 5G communication network facilitates security, low latency, high throughput, high scalability, and cost-effective data storage for the car sharing system. We have formulated the non-cooperative game-theoretic approach to maximize the profit for vehicle owners, and customers also have to pay the minimum price. The formulated approach integrated with blockchain enhances the security of *Block-CPS*. We have implemented the source code of *Block-CPS* on remix IDE to validate the functions involved in it. Finally, the performance of *Block-CPS* has been compared with the traditional approaches in terms of scalability, network latency, data storage cost and its computation, network throughput, profit comparison, communication reliability, and convergence for the optimal payoff between vehicle owners and customers by differentiating between 4G, LTE-A, and 5G networks. Performance of *Block-CPS* shows that the *Block-CPS* is quite secure and reliable.

In future, we will incorporate more real-time scenarios to enable efficient ride sharing for users in a dynamic environment.

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