

PAADAV-SMART PARKING BLOCKCHAIN AND IPFS

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ABSTRACT

In many countries, traffic congestion has become a major challenge, making effective traffic management increasingly difficult for authorities. Issues such as optimal route selection based on congestion levels, timely communication with users, and real-time allocation of parking spaces add to the complexity. Although several approaches have been proposed for predicting parking prices, many existing solutions tend to favor either users or parking owners and often lack adequate security measures. To overcome these limitations, this paper introduces a blockchain and Interplanetary File System (IPFS)-based parking price prediction framework, known as PAADAV. The proposed system enables users to reserve parking spaces in a secure and efficient manner while ensuring transparency, privacy, and trust for both users and parking space providers. The integration of blockchain technology ensures data integrity and security, while IPFS supports decentralized and cost-effective data storage. Additionally, the system incorporates a second-price auction mechanism to determine optimal parking prices, benefiting both users and parking space owners. To evaluate its performance, the PAADAV model is simulated with 100 users and 40 parking slots under different auction strategies. Key performance metrics analyzed include user profit, owner profit, overall system revenue, scalability, computation time, and storage cost. The results demonstrate that the proposed framework not only enhances security and transparency but also provides economic benefits to both users and parking slot owners. Overall, PAADAV offers an efficient and reliable solution for smart parking management in modern urban environments.

INDEX TERMS Blockchain, Smart contracts, Second price auction model, Traffic management

I. INTRODUCTION

TRAFFIC management is one of the challenging tasks that need to be controlled efficiently. It is necessary to regulate the flow of traffic for sustainable traffic management. Traffic congestion is the main reason that it is getting difficult day by day for the drivers to find an empty parking slot, especially during peak hours (1). There are many research studies conducted (2) (3), which state that vehicles looking for free parking slots include approximately 8% of traffic. Drivers spend approximately 3.5 to 14 minutes to find an empty parking slot (4) (5). Even in developing countries, many types of fatal accidents are caused due to traffic congestion (6) (7). There are various studies on vehicle parking prices, and they

It is necessary to ensure security, privacy, and transparency while predicting the parking price so that users can book the parking slot at the optimum price. To mitigate the aforementioned issues, a blockchain-based trusted system is needed to ensure parking price security, confidentiality, and privacy (21) (22). Many researchers discussed the blockchain-based system to mitigate the security and privacy issues of the centralized authority. Some of the works are: Chai *et al.* (16) proposed a consortium-based blockchain model for resource sharing on the internet of vehicles using a consensus mechanism to ensure security in the system. Later, Syed *et al.* (17) presented a blockchain-based framework for vehicle tracking

have shown that a vehicle pays approximately 5 dollars or more, which is a huge amount of total travel cost (8) (9). The survey data of 2013 and 2015 states that on-street parking price on weekdays has increased from 2.00 USD to 4.40 USD per hour (10). Many researchers worldwide discussed the various parking price prediction schemes. Still, with the help of a centralized authority, which is vulnerable to various security issues such as data modification, spoofing, Man-in-the-middle (MitM) attack, etc. (11). Centralized authority can charge high parking prices to allocate a parking slot for users for their benefit (12) (13). These issues can deviate users from utilizing the parking slots leading to the loss of parking slot owners.

integrated with IoT devices.

Authors in (15) presented a blockchain-based layered architecture for a smart parking system to establish trust between users. Then, Hassija *et al.* (12) proposed a distributed parking slot allocation framework based on virtual voting and an adaptive pricing algorithm to allocate the parking slot for users in an optimal way. Later, Jog *et al.* (23) discussed a smart parking technology and automated parking to allocate parking space for users using different technologies such as wireless sensors networks, RFID technology, etc. Then, Simhon *et al.* (14) proposed a smart parking pricing system to predict the occupancy rate of a parking area using a machine learning approach.

Peyal *et al.* in (19) proposed a smart car parking system in urban areas with the help of IoT. The main focus is to reduce traffic congestion and make parking easy for users. Table 1 shows the comparative analysis of various state-of-the-art parking price prediction schemes with the PAADAV PAADAV with or without blockchain. Some of the solutions in (15) (16) (17) (19) given by the researchers are only focusing on enhancing the security of the system. Still, there is no emphasis on optimizing the parking prices for users, profit for vehicle owners, cost-efficiency, scalability, and computation time. Although there are some research works in (12) (14), which emphasize optimizing the parking price for users, they are not focusing on enhancing the security of the system.

Motivated by this, we propose a secure blockchain-based parking price prediction scheme using a second price auction model for sustainable traffic management. The second price auction model optimizes the price for users so that users who booked parking slots with the highest price get the parking slot, but they have to pay the second-highest price. Furthermore, the integrated IPFS with the proposed scheme mitigates the cost storage issues of the blockchain, which further enhances the scalability and reduces computation time and data storage cost of the system. So, users can book the parking slot at the optimized price, reducing traffic congestion, and parking slot owners can also benefit from it.

A. RESEARCH CONTRIBUTIONS

The research contributions of this paper are as follows:

- We propose an IPFS and blockchain-based parking price prediction scheme for cost-efficient and sustainable traffic management.

- We employ a second price auction model to optimize the parking price for users so that parking slot owners can also get benefit from it.
- Finally, we estimate the performance of the PAADAV in terms of profit for users, profit for parking slot owners, revenue of the system, scalability, computation time, and data storage cost of the system.

B. ORGANIZATION OF PAPER

The rest of the paper is organized as follows. Section II discusses the system model and problem formulation. Then, section III shows the proposed model, and Section IV shows the performance evaluation based on the different auction models and blockchain-based results. Finally, Section V concludes the paper. TABLE 2 shows the various symbols and their description used in the blockchain-based proposed scheme using the second price auction model to predict optimum and cost-efficient parking prices for users.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. SYSTEM MODEL

FIGURE 1 shows a blockchain-based parking price prediction scheme (PAADAV) for sustainable traffic management. It consists of a set of users (S_u), the set of parking slots (S_p), and the set of parking slot owners (S_o) communicating through distributed Ethereum network. S_u can communicate with any parking slot owners to book a parking slot by spending an amount from their wallet. S_o can set the reserve price (r_p) so that users can book the parking slots with the bidding price of b_p with the condition that the bidding price of user should be greater than the reserve price of the parking slot.

Users can book the parking slots assigned by the parking slot owners, but they should fulfill some conditions priority. However, before that, the transaction between users and parking slot owners about the parking allocation can be performed efficiently with the help of blockchain through the usage of IPFS. But, data storage in the blockchain tends to be costly due to its feature of storing a whole block of data. Therefore, an IPFS data storage protocol can be incorporated with the blockchain after executing the smart contract for authentication purposes. A smart contract can validate the user's and parking slot owner's data that needs to be stored in the IPFS. If a smart contract finds malicious data in the network, then data access can be denied, ensuring the system's security and confidentiality. Now, certain conditions need to be discussed to allocate the parking slot to the user with a fair parking price. Firstly, users can bid for a parking slot in a network to check whether the current time (ζ_t) is greater than the bidding period (β_p) or not. If ζ_t is greater than β_p , then the second price auction model can be implemented directly. Then, after implementing the second price auction model, there is a condition to check, i.e., whether b_p is greater than r_p or not. If the bidding price (b_p) is greater than the reserve price (r_p), a smart contract can be executed to allocate the

parking slot to the user. Implementing the smart
contract

TABLE 1: A relative comparative analysis of various state-of-the-art parking price schemes with the PAADAV

| Ref | Year | Objective | Blockchain Adoption | Pros | Cons |
|--------|------|--|---------------------|--|---|
| (14) | 2017 | Proposed a smart parking pricing system using machine learning approach | No | Improved accuracy, optimized price | No emphasis on security against malicious attacks |
| (15) | 2018 | Presented a blockchain-based layered architecture for a smart parking system | Yes | Security against DDoS attacks | Security issues against cyber attacks, No focus to optimize parking price |
| (16) | 2019 | Proposed a consortium-based blockchain model in IoV | Yes | Security against double spending attacks and malicious attacks | No efforts to optimize the parking price |
| (17) | 2020 | Investigated a blockchain-based framework for vehicle tracking with IoT devices | Yes | Improved efficiency, security against single point of failure | No focus to optimize the parking price, security issues against DDoS attacks |
| (12) | 2020 | Proposed a distributed parking slot allocation framework to allocate the parking slot for users | No | Optimized parking price, secure against DDoS attacks | No emphasis on security issues against cyber attacks |
| (18) | 2020 | Designed a vehicle parking management integrated with the blockchain and computer vision | Yes | Improved accuracy, secure against bottleneck attack | high data storage cost, no focus on scalability and optimized parking price price |
| (19) | 2021 | Proposed a smart car parking system in urban areas with IoT to make the parking easy for users | No | Reduced traffic congestion, communication in real time | No focus to optimize the parking price, no user friendly environment, security issues against malicious attacks |
| (20) | 2021 | Investigated a blockchain and AI-enabled dynamic parking pricing scheme for an efficient parking | Yes | Fair parking price, reduced traffic congestion | Need to focus on optimizing the parking price |
| PAADAV | 2022 | Proposed a secure blockchain-based parking price prediction scheme | Yes | Optimized parking price, highly secure, and reliable | - |

TABLE 2: Symbols and their description

| Symbols | Description | Symbols | Description |
|------------|-----------------------------------|--------------|------------------------------------|
| S_u | Set of users | N_{as} | Number of available parking slots |
| S_p | Set of parking slots | Ψ | Wallet |
| S_{ρ} | Set of parking slot owners | $Price_u$ | Price for reserving a parking slot |
| r_p | Reserve price | amt | Bidding amount of user |
| b_p | Bidding price | δ_u | Residual amount |
| c | Count of additional parking slots | Space | Additional parking slot |
| ζ | Current time | V_{ρ} | Valuation of the parking slot |
| β_p | Bidding period | Pr_{ρ} | Profit for parking slot owner |
| N_{pr} | Number of parking requests | Pr_u | Profit for the user |
| G_{KB} | Gas price for 1KB of data | E^t | Ethereum price |
| G^{pr} | Standard Gas price | Cos^{prUS} | Cost in USD |

ensures the security in the system to allocate the parking slot to the users efficiently.

There can also be a condition that if ζ_t is less than β_p , then it has to check for the available parking slots, i.e., whether the number of parking requests (N_{pr}) is greater than a number of available parking slots (N_{as}) or not. If $(N_{pr}) > (N_{as})$, then a second price auction model can be implemented to allocate available parking slots to the user. We have to check one more scenario in which if any additional parking slots need to be added; then a smart contract can be executed to add the additional parking slots with its reserve price and count, i.e., $\{r_p, c\}$. Finally, different conditions can be considered to allocate the available parking slot to the user and add any available parking slot in the blockchain network through the intermediary IPFS for improved cost-efficiency.

B. PROBLEM FORMULATION

The proposed scheme consists of set $S \in \{S_u, S_p, S_{\rho}\}$ in which S_u is a set of p users $\{u_1, u_2, \dots, u_p\} \in u_k$ with the bidding prices of $\{b_{p1}, b_{p2}, \dots, b_{ps}\} \in b_{p_u}$, which can be associated with set S_p of r parking

$\{r_{p1}, r_{p2}, \dots, r_{pr}\} \in r_{p_q}$ assigned by the set S_{ρ} of t parking slot owners $\{\rho_1, \rho_2, \dots, \rho_t\} \in \rho_o$ so that users can get a parking slot assigned. u_k can trade with any o^{th} parking slot owner, i.e., ρ_o to book any h^{th} parking slot with the help of their wallet (Ψ). The above mentioned associations can be represented as follows:

$$\Psi_{u_k} \xrightarrow{\rho_h} \Psi_{\rho_o} \tag{1}$$

$$u_k(b_{p_u}) \xrightarrow{\alpha} \sum_{o=1}^t \rho_o \quad t < t, \tag{2}$$

$$\sum_{k=1}^p \rho_o(r_{p_q}) \xrightarrow{\alpha} u_k \quad p < p. \tag{3}$$

where α signifies the relationship between p number of users and t number of parking slot owners.

slots $\{\rho_1, \rho_2, \dots, \rho_r\} \in \rho_h$ with their reserve prices

Users u_k can bid to reserve a parking slot in a distributed network. For that, there is a condition to check if ζ_t is greater than the β_p or not. A smart contract can be implemented to allocate the parking slot based on the second price auction model if the condition is satisfied. In the second-price auction

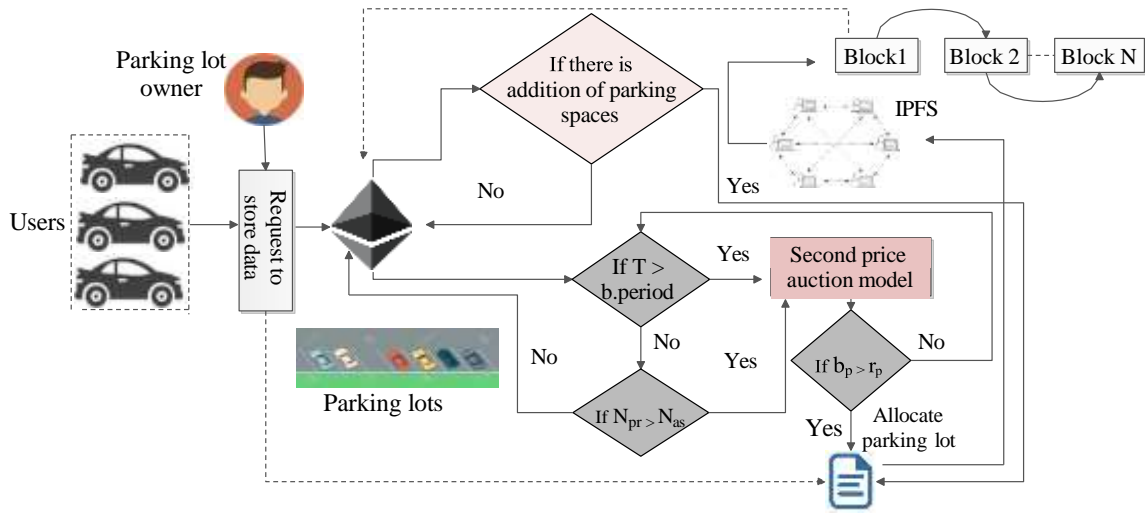


FIGURE 1: PAADAV: The system model.

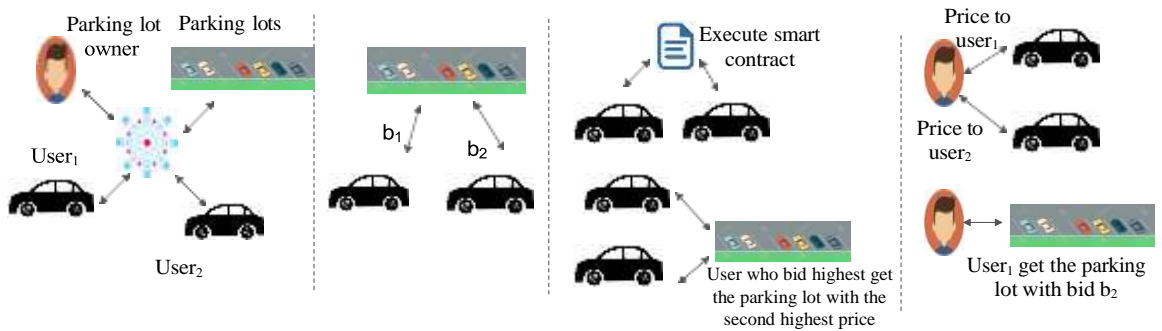


FIGURE 2: PAADAV: The Proposed model

(IDE) to show the improved and cost-efficient parking slot

0
 Fixed price First price Second price

FIGURE 4: Profits for owners from different models.

III. PERFORMANCE EVALUATION BASED ON THE DIFFERENT AUCTION MODELS AND BLOCKCHAIN

In this section, the performance evaluation of the dynamic pricing allocation scheme is analyzed based on the different auction models such as fixed price, first-price auction model with the proposed second-price auction model. We have also analyzed the performance of the blockchain-based proposed scheme in terms of scalability, computation time, and data storage cost of the system. The evaluation of the results has been analyzed in Remix integrated development environment

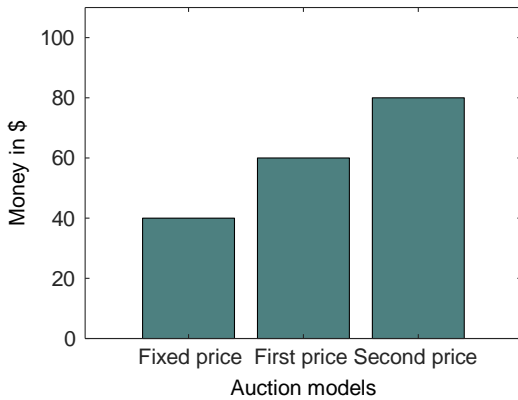


FIGURE 5: Revenue from different models.

booking in favor of users and parking slot owners. The results based on the different auction models and blockchain, along with the simulation, can be represented as follows:

A. SIMULATION

1) Dataset Generation and Initial Experiment Setup

The analysis of the proposed scheme has been simulated over the Remix IDE (25). The smart contracts of the proposed scheme are developed, compiled, run, and tested over the Remix IDE using solidity source code (26). The experiment has been simulated for 100 users with 40 parking slots. We have randomly generated a valuation of the parking slot for a u_i corresponding to his purchasing power using a Gaussian distribution with a mean of 50 and a variance of 15 (30% of the mean). In addition, the reserve prices rp_j of the parking slots have been randomly generated with a mean of 40 and a variance of 10 (25% of the mean). The second price auction model simulation has been performed in python 3.2 with the help of generated dataset for 100 users and 40 parking slots, along with the generated reserve prices of the parking slot.

2) Bids and Prices in Different Models

The second price auction model is a revealing demand model. Therefore, bid b_{p_u} of a parking slot by a u_k in a second price auction model has been assumed to be equal to the valuation V_{ρ_n} . In a first-price auction model, users do not reveal they are true price. So, a bid b_{p_u} of a u_k , which is less than valuation V_{ρ_n} has been randomly selected. The simulation results in the first pricing model have been averaged over multiple iterations.

A profit rate of 15% over the r_p has been assumed for determining the price in simulating a fixed price model. The prices for a parking slot in a first-price and second-price auction model have been determined based on the auction allocation scheme. A user with the highest bid is allocated a parking slot with the highest r_p in the auction allocation scheme. In a second price auction model, the price $Price_r$ of a parking space is the second-highest bid. In the first-price

3) Evaluation of profit based on different auction models

Profit for a u_k can be defined as follows

- Profit for the user $Pr_{u_k} = 0$, if a user is not allocated a parking slot.
- Profit for the user $Pr_{u_k} = V_{\rho_n} - Price_r$, if user is allocated a parking slot.

where $Price_r$ is the price of the r^{th} , parking slot allocated based on the different models. Profit for users is relatively less when they are quoted a price closer to their valuations. As auction-based models help reflect consumer demand at a time, thus it helps in driving the prices up, which are closer to the users' valuation. As the second price auction model is auction model, the price $Price_r$ of the parking space is the bid's value.

a revealing demand mode, the bids in a second price auction model are closer to the users' valuation. Therefore, driving the prices of the parking slots high, the net profit for all users is the least in the second price auction model.

Profit for parking slot owners: Profit for a r^{th} parking slot can be defined as follows

- Profit for r^{th} parking slot $Pr_{\rho} = 0$, if the parking slot is not allocated to a user.
- Profit for r^{th} parking slot $Pr_{\rho} = Price_r - rp_r$, if user is allocated a parking slot

where $Price_r$ is the price of the r^{th} parking slot allocated based on the different models, higher prices help increase the net profit for parking slot owners. As the prices go high in a second-price auction model, parking slot owners have the highest net profit. As discussed in the previous scenario, the auction-based models help drive the prices up, thus reducing the profit for users. It helps transfer the profit from the users to the owners of the parking slots. As the profit for users is least in the second price auction model, the net profit for parking owners is highest according to the second price auction model.

4) Revenue

Revenue can be defined as follows:

- Revenue = $Price_r * x$
- $x = 0$, if r^{th} parking slot is not allocated.
- $x = 1$, if the r^{th} parking slot is allocated to a user.

where $Price_r$ is the price of the r^{th} parking slot allocated based on the different models. As the prices of the allocated parking slots increase, the system's total revenue increases. As previously mentioned, the prices are higher in a second price model. Thus, it has the highest revenue among all the auction models.

5) Confidence Interval for First Price

The first price auction model has calculated the parameters, i.e., revenue and profit. As in a first-price auction model, the bids submitted by the users are not equal to true bids, i.e., true valuations V_{ρ_h} . So, we have randomly generated bids for the users corresponding to the valuations. The different parameters have been calculated for 25 samples and their corresponding 95% confidence intervals. The red horizontal line represents the mean, i.e., values for different parameters

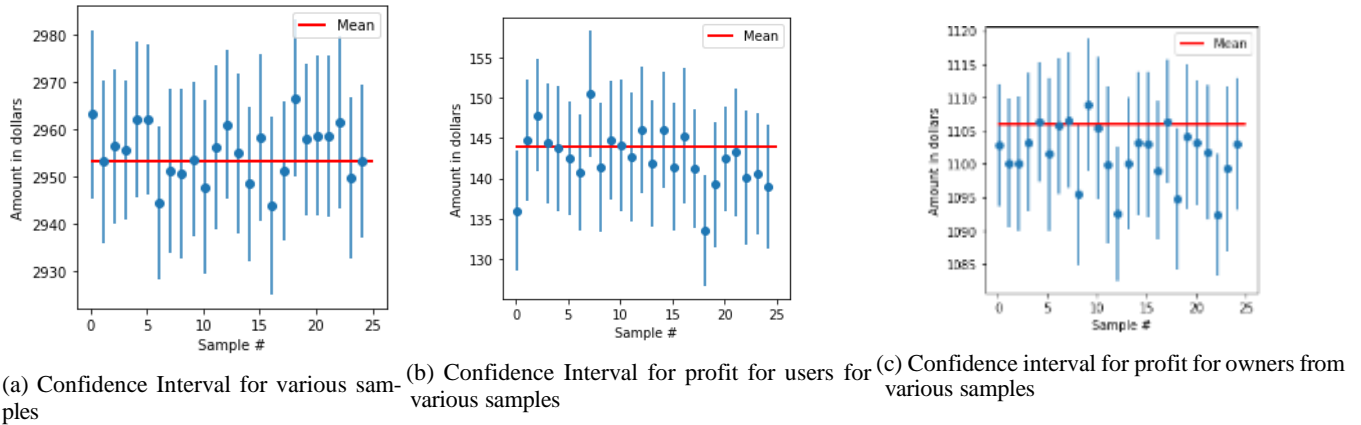


FIGURE 6: Confidence interval for the first price

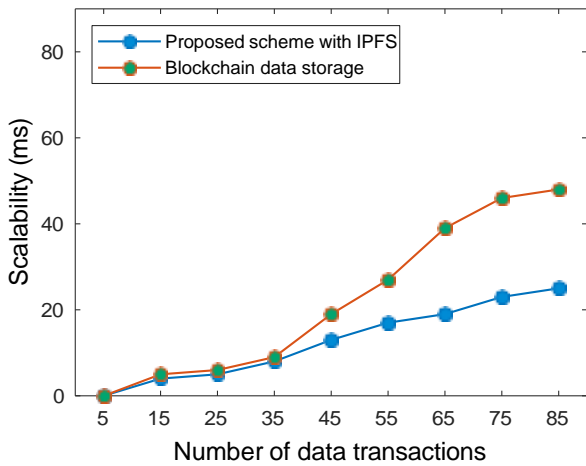


FIGURE 7: Scalability analysis.

The usage of IPFS with the blockchain-based proposed scheme proves to be cost-efficient for the users and parking slot owners involved in the system. FIGURE 7 distinguishes

(a) Security analysis of PAADAV over smartcheck

(b) Security analysis over the smartcheck by default

FIGURE 8: Security analysis of the PAADAV over smartcheck tool

calculated by the first price auction model. As shown in FIGURE 6, means lie in most of the confidence intervals of different samples. Thus, the values calculated by the first price auction model help predict the simulation results accurately.

6) Scalability

between the proposed scheme with IPFS and blockchain data storage in terms of scalability. It can be perceived from the graph that the scalability of the proposed scheme with IPFS tends to provide more efficient data storage than the usage of blockchain as the number of transactions increases. However, the graph shows that the scalability seems to be in the same alignment due to the involvement of a lesser number of transactions between users and parking slot owners for both the data storage.

7) Computation time

This section discusses the computation time of the proposed scheme to store and retrieve parking allocation data of users and parking slot owners from the blockchain. Foremost, the computation time of uploading the data in the blockchain directly after authentication with a smart contract can be determined

```
C:\Users\hp\Desktop\Parking.sol
jar:file:/C:/Users/hp/AppData/Roaming/npm/node_modules/@smartdec/
PRAGMAS_VERSION
patternId: 23fc32
severity: 1
line: 1
column: 23
```

(28). Now, it can be observed that IPFS consumes slightly higher computation time to store data than blockchain due to the involvement of an intermediary

```
C:\Users\hp\Desktop\Parking.sol
jar:file:/C:/Users/hp/AppData/Roaming/npm/node_modules/@smartdec
```

its feature of hash data storage reflects a quite low data retrieval time than blockchain, which is being discussed further. As data retrieval time of blockchain incorporated with IPFS or without IPFS should be calculated to show the benefits of the low data storage cost protocol. Therefore, the computation time involved in

the data retrieval from the blockchain for users and parking slot owners can be determined as $6 * 10^5$ ms (29), with the help of the SHA-256 algorithm. On the other hand, the computation time of the data retrieval from blockchain through an intermediary IPFS is computed as 75ms (27), which seems to be quite improved and low than the traditional schemes with blockchain.

8) Data storage cost

In this section, we have considered the IPFS with the Ethereum blockchain to obtain the efficient data storage cost

so that users and parking slot owners can access the IPFS for data storage after validation with the smart contract. The cost associated with the blockchain to store data is somewhat high, making the system unfavorable for the users and parking slot owners. We can find the cost of blockchain with the help of the gas price of a single word of 256 bits. The gas price for the single word and 1KB of data can be computed as:

$$1wd = 20,000 \text{ Gas} (G_s = 20K) \quad (13)$$

$$G_{KB} = (2^{10}/256) * 20,000 \text{ Gas} \quad (14)$$

Furthermore, cost (Cos^P) for data storage of P number of word in blockchain can be determined with the parameters standard gas price (G_s^{pr}) and Ethereum price (E_t^{pr}) which are 23.186 *gwei* and 232.96 USD. The cost for P words can be calculated considering the two :

$$1E^t = 10^9 \text{gwei and } Exp = (p * G_s)/10^9 \quad (15)$$

Therefore, the computation of cost (data storage of P words in USD) can be written as follows:

$$Cos^{PUS} = (G_s^{pr} * Cos_p) * E_t^{pr} \quad (16)$$

Finally, it can be concluded that blockchain incurs high data storage costs than incorporated IPFS with the blockchain. Therefore, the blockchain-based proposed scheme with the IPFS tends to cost optimization for users and parking slot owners' data storage (30).

B. SECURITY VERIFICATION OF THE PAADAV

In this section, the smartcheck security tool has been used for security analysis of the smart contracts designed for the PAADAV. We have implemented the source code from the Ethereum platform to detect the security-related issues in the PAADAV. FIGURE 8b depicts how the smartcheck tool verifies that the source code of the PAADAV does not contain any threat or vulnerability. But, smartcheck tool generates one severity in the source code by default as depicted in the FIGURE 8a (31). We have removed that identified severity from the source code as depicted in FIGURE 8b.

IV. CONCLUSION

In this paper, a blockchain-based parking price prediction scheme, PAADAV, is proposed for sustainable traffic management. First, we explored the traditional systems with or without blockchain to get insights into their security, privacy, and optimized parking price issues. Then, we employ the second price auction model to predict the optimized price for users to reserve a parking slot conveniently and parking slot owners can also benefit from it. We have performed the security analysis of the PAADAV by implementing source code on Remix IDE using a smart contract. Finally, the performance of the PAADAV has been evaluated in terms of profit for users, profit for parking slot owners, and overall revenue of the

system considering different auction models and blockchain-based results in terms of scalability, computation time, and

data storage cost. Results show that the proposed scheme is more secure, cost-efficient, and beneficial for users and parking slot owners than the traditional schemes.

In the future, we will explore the scenario in which multiple bidders bid the same amount simultaneously to reserve the parking slot with the optimized price using game-theoretical aspects.

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