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Blockchain and Zero-Sum Game-based Dynamic Pricing Scheme for Electric Vehicle Charging

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***Abstract*—This paper proposes a zero-sum game theory and blockchain-based secure and decentralized dynamic pricing scheme for electric vehicle charging. It aims to secure data sharing between electric vehicles and charging stations. We integrate the sixth-generation (6G) communication network to enable data transactions between electric vehicles and charging stations with low latency and high reliability. We employ a zero-sum game theory approach to maximize the payoff of electric vehicles and charging stations. The performance of the proposed system with 6G is evaluated by comparing it with 5G and 4G traditional networks. The performance evaluation of the proposed system has been analyzed with various parameters latency, profit for electric vehicles, profit for charging station, and optimal payoff of the system. The results show that the proposed system is highly secure and reliable than traditional systems.**

***Index Terms*—Blockchain, Electric vehicle, Zero-sum game theory, Profit, Payoff, Latency.**

I. Introduction

Over the past decade, the transportation system has completely transformed the quality of living for people. As people get the privilege to travel worldwide with the number of increased fossil-fuel-powered vehicles on the road [1]. Although, as estimated in [2], fossil-fuel vehicles on the road are the reason for increased global warming due to the release of approximately 30% of greenhouse gases, mainly CO_2. Therefore, the transportation system has gradually adapted the electric vehicles instead of conventional fossil-fuel vehicles due to its various advantages such as reduced air pollution, reduced global warming, environment-friendly, and reduced prices for charging [3]. However, a huge number of EVs on the road increases charging demand, which means more CS infrastructure. But, to mitigate the above-mentioned issue, we need to develop more power plants, which is quite expensive for users [4]. So, with the increase in the number of EVs, charging prices can also vary depending on the crowd or area, i.e., fluctuations in charging price based on the town or metro city [5]. Hence, it is necessary to schedule EVs considering the charging prices as high prices can cause loss to the EVs and low prices cannot be favourable for CS.

To mitigate the above mentioned issues, some authors/researchers have proposed the EVs charging scheme, but with the help of a centralized cloud server that can't store data of users insecure way. For example, there can be various security attacks against the data, such as modification attack, integrity attack, man-in-the-middle attack etc. [2]. These security issues can discourage EVs from charging at the charging station.

So, to meet the aforementioned issues, a blockchain-based decentralized and trustable framework [6] is crucial to enhance the security in the system so that EVs can be motivated enough for charging at the CS [7][8]. Some of these works are: Cao *et al.* [9] discussed a blockchain-based EV charging reservation approach to enhance security in the system. Then, Wang *et al.* [10] proposed an efficient charging scheme for EVs in vehicular energy networks using blockchain. Further, they introduce a game-based theory approach to enhance user profit.

Then, authors in [11] studied a blockchain-based energy trading scheme for EVs. They are mainly focusing on securing the data of users against various attacks. Later, Li *et al.* [12] presented a blockchain and fog computing-based EVs charging scheme to ensure the privacy and transparency of users while charging. Later, Gabay *et al.* [13] investigated the blockchain and zero-knowledge proofs method to ensure authentication and privacy for EVs. They have adapted a token-based approach to ensure anonymity in the system.

Most of the secure blockchain-based solutions presented by the researchers can come across various issues such as latency, cost-efficiency, the optimal payoff of the system, and profit for EVs and CS. They have also not discussed dynamic charging prices for optimal payoff. In some of the literature [9] [10], they have considered optimizing the cost for users, but without any involvement of dynamic charging prices. Motivated from this, we introduce a blockchain-based dynamic pricing scheme for EV charging using a zero-sum game theory approach. The zero-sum game theory approach aims to optimize the payoff for EVs and CS with the existence of a saddle point so that both users can be satisfied in terms of profit. To address the issues of latency, a 6G network is adapted with blockchain due to its prominent characteristics, i.e., high data speed ($< 10Gbps$) and low latency ($< 1ms$) [14] to ensure efficient data transactions between EVs and CS [15].

Primarily, the blockchain-proposed system focuses on enhancing security, transparency, efficiency, and confidentiality in the system [16]. In the proposed system, EVs and CS can store their data in the blockchain for charging and security purpose. But, data storage in the blockchain is quite costly for users. Therefore, to address the data storage issue, we have employed a decentralized IPFS free of cost data storage protocol so that EVs and CS can store their data in a cost-efficient way [17].

A. Motivation

- As per the literature, many researchers have discussed the blockchain-based EVs charging scheme while ignoring the latency and optimal payoff for EVs and CS.

- Some researchers have discussed the optimised price but without considering the effect of dynamic charging prices in charging. Motivated from this, we have introduced a blockchain-based dynamic pricing scheme for EV charging using a zero-sum game theory approach.
- Thus, there is a need to propose a blockchain-based dynamic pricing scheme with a 6G network to enhance the latency and efficiency of the system.

B. Research contributions

The research contributions of this paper are as follows.

- We propose a secure and efficient blockchain incorporated with an IPFS-based dynamic pricing scheme for electric vehicles charging over a 6G communication network.
- We formulate a zero-sum game theory approach to optimize the profit for EVs and CS to make the system profitable.
- Lastly, we evaluate the performance of the proposed system considering the parameters such as latency, the optimal payoff of the system, and profit for EVs and CS.

C. Organization

The rest of the paper is organized as follows. Section II presents the system model and problem formulation. Section III describes the zero-sum game theory approach. Results of the proposed system is presented in Section IV and finally, the paper is concluded in the Section V.

II. System model and problem formulation

A. System model

Fig.1 presents a blockchain-based dynamic pricing scheme for electric vehicle charging. It comprises of three components, which include component EVs (C_ν) embedded with the smart meters (Φ_ν), component CSs (C_ζ) equipped with the RFID sensors indicated by π, and component price monitoring entity (C_{Ω^E}) communicating via blockchain over 6G network. The energy level indicator associated with the EVs indicates the available energy ($\Gamma_\nu \in \mathbb{Q}$), which is being detected using smart meters Φ attached with them. Now, component C_ν along with their Γ_ν arrived at the CS, which is assigned with the charging price of (ρ_ζ^{dp}) that is varying based on the various factors. It means price associated with the CS can vary according to the number of EVs arriving at the CS and day, i.e., weekday or weekend. The 6G communication network is employed to make the system efficient and reliable. The incorporated IPFS storage protocol ensures that data can be stored in the blockchain in cost-efficient way.

The main aim of the proposed system is to ensure privacy, security, confidentiality, and transparency in the system. For that, we have introduced a price monitoring entity Ω^E to monitor the prices of CS if it crosses the maximum threshold price ($\Gamma_{\rho_\zeta^{dp}}$). Otherwise, if prices for CS hikes up unnecessary, then EVs can lose interest to charge their vehicles, which can also cause a loss of CS. Price monitoring entity monitors the price of CS by assigning them the token β_ζ. As EVs are only arriving with the available energy for charging, there is no need to monitor or authenticate them. However, if EVs and CS want to become valid blockchain participants, then a smart contract is executed to legitimize them for their request. A zero-sum game theory approach is devised to optimize the charging price ρ_ζ^{dp} for EVs and CS should also get profit from it. The components interact over 6G communication networks, which facilitates ultra-high reliable and ultra-low latency data transactions so that EVs can charge their vehicles efficiently.

Fig.1 shows the working of the layered architecture of a blockchain-based dynamic pricing scheme for electric vehicle charging. The architecture consists of three layers: (1) EV charging layer, (2) Price monitoring and data communication layer, and (3) Blockchain layer. These three layers can be explained as follows:

1) EV Charging Layer: This layer consists of EVs arriving at the CS along with their associated hash keys λ_ν and Λ_ζ to charge their vehicles based on their available energy Γ_ν. Now, EVs with their Γ_ν can decide for charging based on the dynamic prices associated with CS. It means prices for charging can fluctuate based on the day on which EVs arrive and the number of EVs arrive at the CS. Now, EVs with their data about the available energy and CS with their dynamic prices ρ_ζ^{dp} can request to store their data in the IPFS. The data can be stored in the IPFS with the help of the price monitoring entity Ω^E introduced in the price monitoring and data communication layer. For that purpose, Ω^E can observe the ρ_ζ^{dp} of CS by assigning them the threshold price $\Gamma_{\rho_\zeta^{dp}}$ along with their Λ_ζ. The frequent fluctuation, i.e., high charging prices of CS can disinterest EVs for charging. So, Ω^E monitors whether ρ_ζ^{dp} crosses the threshold price $\Gamma_{\rho_\zeta^{dp}}$ or not. If it lies below the threshold price, then CS can store their data about the charging price in the IPFS, otherwise, it is not authenticated to store the data in IPFS. Now, to store the data of EVs and CS in IPFS, they have to transit through the price monitoring and data communication layer to fulfill some more conditions.

2) Price Monitoring and Data Communication Layer: In the EV charging layer, EVs with available energy and CS with their charging price being monitored by the price monitoring entity has to go through the price monitoring and data communication layer. This layer involves the execution of a smart contract to authorize the EVs and CS along with their hash keys λ_ν and Λ_ζ, so that they can store their data in the IPFS. Also, monitoring charging prices ensures that both EVs and CS should not suffer from any loss. The data transmission of EVs and CS can be carried out reliably and securely over the 6G communication network with high availability, high data speed, and low latency features.

3) Blockchain Layer: It is the security layer of the proposed system, which mainly focuses on securing the data transactions of EVs and CS for charging. As smart contract already validated them to reserve their data in the IPFS. Now, they can request to append the stored data in the blockchain, i.e., to become a valid member of the blockchain. But before that, as they get the privilege to reserve their data in IPFS, IPFS provide them with the hash keys Θ_ν^{hk} and Θ_ζ^{hk}. Then, EVs and CS with their hash keys can request to add their data to the blockchain. For that, if hash keys associated with the EVs and CS coincide with the hash (ha^{bl}) of blockchain. Then, data can be appended to the blockchain successfully. Algorithm 1 shows the procedure to append data of *u* number of EVs and *p* number of CS to the blockchain with the time complexity of O(u) and O(p). The time complexity of the Algorithm 1 depends on the data associated with the number of EVs and CS that needs to be appended to the blockchain.

Algorithm 1 Algorithm to append data to the blockchain.

Input: Θ_{ν}^{hk}, ha^{bl} Θ_{ζ}^{hk}, $IP_{(hkey)}$
Output: Data appended to the blockchain

procedure APPEND__BLOCKCHAIN(ν,ζ, Θ_{ν}^{hk},Θ_{ζ}^{hk},Pm^{e})
  if $C \in C_{\nu_v}$ **then**
    for $i = 1, 2, \ldots, u$ **do**
      $IP_{(hkey)} \leftarrow$ AppendData(ν_v)
      Execute smart contract
      if λ_{ν} $==$ $authentic$ **then**
        $\nu_v \xleftarrow{\Theta_{\nu}^{hk}} IP_{(hkey)}$
        $blockchain \leftarrow$ Data_to_append(ν_v)
        if $\Theta_{\nu}^{hk} \in ha^{bl}$ **then**
          Data appended to the blockchain
        else
          Invalid hash
        end if
      else
        Invalid user
      end if
    end for
  else if $C \in S_{\zeta}$ **then**
    for $j = 1, 2, \ldots, p$ **do**
      $IP_{(hkey}$ $\leftarrow$ Appenddata(ζ)
      $\zeta_q \leftarrow Pm^{e}$
      Execute smart contract
      if $\rho_{\zeta}^{dp} < \Gamma_{\rho_{\zeta}^{dp}}$ **then**
        $\zeta_n \xleftarrow{\Theta_{\zeta}^{hk}} IP_{(hkey)}$
        $blockchain \leftarrow$ DataReq_to_append(ζ_q)
        if $\Theta_{\zeta}^{hk} \in ha^{bl}$ **then**
          Data appended to the blockchain
        else
          Invalid hash
        end if
      else
        Invalid charging price
      end if
    end for
  end if
end procedure

B. Problem Formulation

The proposed system involve various components, i.e., component C_{ν} consists of set of u number of EVs $\{\nu_1, \nu_2, \ldots, \ldots, \nu_u\} \in \nu_v$ with their available energy Γ_{ν} arriving at a CS ζ to charge their vehicles by trading money from their wallet (ξ). Further, component C_{Ω} consists of p number of price monitoring entities Pm^{e} $\{\Omega_1, \Omega_2, \ldots, \ldots, \Omega_p\} \in \Omega_g$ communicating with a CS ζ to monitor the charging price ρ_{ζ}^{dp} so that prices should be in favor of both EVs and CS. The above mentioned associations can be represented as follows:

$$\xi^{\nu_v} \rightarrow \xi^{\zeta} \tag{1}$$

$$\sum_{v=1}^{u'} \nu_v(\Gamma_{\nu}) \xrightarrow{\sigma} \zeta(\rho_{\zeta}^{dp}) \;\; and \;\; \zeta(\rho_{\zeta}^{dp}) \xrightarrow{\sigma} \sum_{v=1}^{u'} \nu_v(\Gamma_{\nu}) \tag{2}$$

$$\zeta(\rho_{\zeta}^{dp}) \xrightarrow{\sigma'} \sum_{g=1}^{p'} \Omega_g(\Gamma_{\rho_{\zeta}^{dp}}) \tag{3}$$

$$u' \leq u, \;\; p' \leq p, \;\; v \geq 0, \;\; g \geq 0 \tag{4}$$

where σ signifies the association of u' number of EVs and CS for charging. σ' denotes the relationship between p' number of price monitoring entities Pm^{e} and CS. Now, EVs and CS want to store their data in the IPFS, but before that, the price monitoring entity inspects the change in charging prices of CS. For EVs, there is no need to authenticate them as they are arriving with the data, i.e., available energy at a CS, which can't tamper with the system's security. For CS, price monitoring entity Pm^{e} observes the fluctuation in dynamic charging prices ρ_{ζ}^{dp} based on the various parameters. The parameters are number of EVs (N_{ν_v}) arriving at the CS and day (α), whether it is weekday (We^{α}) or weekend (Wd^{α}). Now, we have classified parameter day into three time zone (τ), i.e., morning ($\tau_1 - \tau_2$), afternoon ($\tau_3 - \tau_4$), and evening ($\tau_5 - \tau_6$) according to the We^{α} or Wd^{α}. The above-mentioned entities can be represented as follows:

$$\alpha = \begin{cases} We^{\alpha}, & \text{when day is weekday} \\ Wd^{\alpha}, & \text{when day is weekend} \end{cases} \tag{5}$$

$$\tau(We^{\alpha}, Wd^{\alpha}) = \begin{cases} \tau_1 - \tau_2, & \text{if timezone is morning} \\ \tau_3 - \tau_4, & \text{if timezone is afternoon} \\ \tau_5 - \tau_6, & \text{if timezone is evening} \end{cases} \tag{6}$$

So, dynamic charging price ρ_{ζ}^{dp} of CS can vary based on these parameters. But, the charging price should be assigned in such a way that both EVs and CS should be satisfied with it in terms of optimized price and profit. The charging price of CS depends upon the number of EVs (N_{ν_v}) and day α. It further

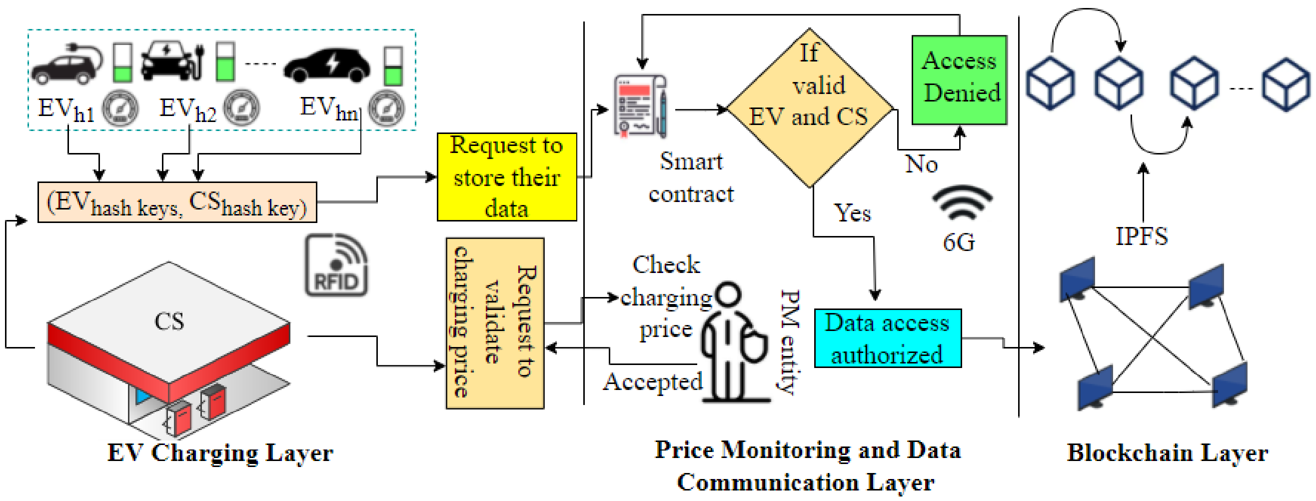

Fig. 1: System model.

depends upon one more situation, i.e., whether the number of EVs entering at the CS is greater than the threshold number (δ_{ν}^{Th}) or not. If it is greater than threshold number, then ρ_{ζ}^{dp} increase by factor x and $x^{'}$ in timezone morning $\tau_1 - \tau_2$ and evening $\tau_5 - \tau_6$ in case of weekday We^{α}. For weekend, ρ_{ζ}^{dp} increase by the factor y and $y^{'}$ in case of timezone afternoon $\tau_3 - \tau_4$ and evening $\tau_5 - \tau_6$. So, the increase in charging price $\rho_{\zeta}^{dp}(Hp)$, $\rho_{\zeta}^{dp}(Hp^{'})$, $\rho_{\zeta}^{dp}(Hp^{''})$, and $\rho_{\zeta}^{dp}(Hp^{'''})$ based on the parameters in case of EVs greater than δ_{ν}^{Th} can be represented as follows:

$$\rho_{\zeta}^{dp} \rightarrow \{N_{\nu_v}, \alpha(We^{\alpha}, Wd^{\alpha}\} \tag{7}$$

$$\rho_{\zeta}^{dp}(Hp) \xrightarrow{\eta} \rho_{\zeta}^{dp} + x(\alpha(We^{\alpha}(\tau_1 - \tau_2))) \tag{8}$$

$$\rho_{\zeta}^{dp}(Hp^{'}) \xrightarrow{\eta} \rho_{\zeta}^{dp} + x^{'}(\alpha(We^{\alpha}(\tau_5 - \tau_6))) \tag{9}$$

$$\rho_{\zeta}^{dp}(Hp^{''}) \xrightarrow{\eta} \rho_{\zeta}^{dp} + y(\alpha(Wd^{\alpha}(\tau_3 - \tau_4))) \tag{10}$$

$$\rho_{\zeta}^{dp}(Hp^{'''}) \xrightarrow{\eta} \rho_{\zeta}^{dp} + y^{'}(\alpha(Wd^{\alpha}(\tau_5 - \tau_6))) \tag{11}$$

Similarly, if number of EVs are less than the threshold value, then there is decrease in charging price of CS based on the weekday or weekend. So, For weekend, ρ_{ζ}^{dp} decrease by the factor z and $z^{'}$ in timezone afternoon $\tau_3 - \tau_4$ and evening $\tau_5 - \tau_6$. Alternatively, ρ_{ζ}^{dp} decrease by factor w and $w^{'}$ in timezone morning $\tau_1 - \tau_2$ and evening $\tau_5 - \tau_6$ in case of weekday We^{α}. So, the decrease in charging price $\rho_{\zeta}^{dp}(Lp)$, $\rho_{\zeta}^{dp}(Lp^{'})$, $\rho_{\zeta}^{dp}(Lp^{''})$, and $\rho_{\zeta}^{dp}(Lp^{'''})$ based on the parameters in case of EVs greater than δ_{ν}^{Th} can be represented as follows:

$$\rho_{\zeta}^{dp}(Lp) \xrightarrow{\eta} \rho_{\zeta}^{dp} - z(\alpha(We^{\alpha}(\tau_1 - \tau_2))) \tag{12}$$

$$\rho_{\zeta}^{dp}(Lp^{'}) \xrightarrow{\eta} \rho_{\zeta}^{dp} - z^{'}(\alpha(We^{\alpha}(\tau_5 - \tau_6))) \tag{13}$$

$$\rho_{\zeta}^{dp}(Lp^{''}) \xrightarrow{\eta} \rho_{\zeta}^{dp} - w(\alpha(Wd^{\alpha}(\tau_3 - \tau_4))) \tag{14}$$

$$\rho_{\zeta}^{dp}(Lp^{'''}) \xrightarrow{\eta} \rho_{\zeta}^{dp} - w^{'}(\alpha(Wd^{\alpha}(\tau_5 - \tau_6))) \tag{15}$$

where η denotes the variation of charging price with the parameters Wd^{α} and We^{α}. So, we have discussed the variation of charging price based on the various parameters. Ω^{E} can monitor the charging price of CS, according to which if it fluctuates and crosses threshold price $\Gamma_{\rho_{\zeta}^{dp}}$, then the price monitoring entity disapprove CS from storing the data in the IPFS. If it is authenticated, then EVs and CS can get their data stored in the IPFS by getting validation from the smart contract. If a smart contract validates them, then they can get the hash keys $\{\Theta_{\nu_1}^{hk}, \Theta_{\nu_2}^{hk}, \ldots, \ldots, \Theta_{\nu_u}^{hk}\} \in \Theta_{\nu_v}^{hk}$ and Θ_{ζ}^{hk} provided by the IPFS to return the favor of storing the data. The above associations can be mentioned as follows:

$$\nu_v(\Gamma_{\nu}) \xrightarrow{\epsilon} \sum_{v=1}^{l} \Theta_{\nu_v}^{hk} \quad and \quad \zeta(\rho_{\zeta}^{dp}) \xrightarrow{\epsilon} \Theta_{\zeta}^{hk} \tag{16}$$

$$v > 0, \quad l \leq u \tag{17}$$

As, EVs and CS has already stored their data in the IPFS. Now, there can be another request of EVs and CS to append their data to the blockchain, i.e., to become valid member of the blockchain network. For that, hash keys $\Theta_{\nu_v}^{hk}$ and Θ_{ζ}^{hk} of EVs and CS provided by IPFS should be in alignment with hash of the blockchain.

Algorithm 2 Zero-sum game theory algorithm to optimize payoff for EV and CS

Input: $P, \delta_{\nu}^{Th}, \nu, \zeta$
Output: $\Pi_{(\nu,\zeta)}^{s}(P_{s*}^{\nu}, P_{s*}^{\zeta})$

procedure OPT_PAYOFF($N, \rho_{\zeta}^{dp}(Max), \rho_{\zeta}^{dp}(Min)$)
  if $\nu > \delta_{\nu}^{Th}$ **then**
    $\rho_{\zeta}^{dp}(Hp) \xrightarrow{\eta} \rho_{\zeta}^{dp} + x(\alpha(We^{\alpha}(\tau_1 - \tau_2)))$
    $\rho_{\zeta}^{dp}(Hp^{'}) \xrightarrow{\eta} \rho_{\zeta}^{dp} + x^{'}(\alpha(We^{\alpha}(\tau_5 - \tau_6)))$
    $\rho_{\zeta}^{dp}(Hp^{''}) \xrightarrow{\eta} \rho_{\zeta}^{dp} + y(\alpha(Wd^{\alpha}(\tau_3 - \tau_4)))$
    $\rho_{\zeta}^{dp}(Hp^{'''}) \xrightarrow{\eta} \rho_{\zeta}^{dp} + y^{'}(\alpha(Wd^{\alpha}(\tau_5 - \tau_6)))$
  else
    $\rho_{\zeta}^{dp}(Lp) \xrightarrow{\eta} \rho_{\zeta}^{dp} - z(\alpha(We^{\alpha}(\tau_1 - \tau_2)))$
    $\rho_{\zeta}^{dp}(Lp^{'}) \xrightarrow{\eta} \rho_{\zeta}^{dp} - z^{'}(\alpha(We^{\alpha}(\tau_5 - \tau_6)))$
    $\rho_{\zeta}^{dp}(Lp^{''}) \xrightarrow{\eta} \rho_{\zeta}^{dp} - w(\alpha(Wd^{\alpha}(\tau_3 - \tau_4)))$
    $\rho_{\zeta}^{dp}(Lp^{'''}) \xrightarrow{\eta} \rho_{\zeta}^{dp} - w^{'}(\alpha(Wd^{\alpha}(\tau_5 - \tau_6)))$
  end if
  Players $\{\nu, \zeta\}$ with strategy P_s^{ν} and P_s^{ζ}
  $\rho_{\zeta}^{dp}(Max) = \{(\rho_{\zeta}^{dp}(Hp), \rho_{\zeta}^{dp}(Hp^{'}), \rho_{\zeta}^{dp}(Hp^{''}), \rho_{\zeta}^{dp}(Hp^{'''}))\}$
  $\rho_{\zeta}^{dp}(Min) == \{\rho_{\zeta}^{dp}(Lp), \rho_{\zeta}^{dp}(Lp^{'}), \rho_{\zeta}^{dp}(Lp^{''}), \rho_{\zeta}^{dp}(Lp^{'''})\}$
  if $\{\Pi_{(\nu,\zeta)} == (P_{s_1}^{\nu}, P_{s_1}^{\zeta})\}$ **then**
    $\nu((\Gamma_{\nu}))(\rho_{\zeta}^{dp}(Max)) \xrightarrow{\iota} \rho_{\zeta}^{dp}(Min)$
  else if $\{\Pi_{(\nu,\zeta)} == (P_{s_1}^{\nu}, P_{s_2}^{\zeta})\}$ **then**
    $\nu((\Gamma_{\nu}))(\rho_{\zeta}^{dp}(Max)) \xrightarrow{\iota} \rho_{\zeta}^{dp}(Min)$
    $\zeta(\rho_{\zeta}^{dp})(\rho_{\zeta}^{dp}(Min)) \xrightarrow{\iota} \rho_{\zeta}^{dp}(Max)$
  else
    $\zeta(\rho_{\zeta}^{dp})(\rho_{\zeta}^{dp}(Min)) \xrightarrow{\iota} \rho_{\zeta}^{dp}(Max)$
  end if
  Players $\{\nu, \zeta\}$ with strategy P_{s*}^{ν} and P_{s*}^{ζ}
  $\rho_{\zeta}^{dp}(Min) < \Pi_{(\nu,\zeta)}^{s}(P_{s*}^{\nu}, P_{s*}^{\zeta}) < \rho_{\zeta}^{dp}(Max)$
  Both the players get the optimized payoff $\Pi_{(\nu,\zeta)}^{s}(P_{s*}^{\nu}, P_{s*})$
end procedure

III. Zero-Sum Game Theory Approach

In the proposed system, a zero-sum game theory approach has been considered to optimize the profit for EV and CS. The game should be played in such a way that EV can also get the CS with optimized price and CS should also not suffer from any loss. But there is a condition for applying the zero-sum game theory approach. As we have already discussed the variation in charging price is based on the parameters α, We^{α}, and Wd^{α}. So, if EVs arrive with available energy greater than threshold energy, they can choose whether to charge their vehicle or not based on the charging price. It means if the charging price hikes up and crosses the threshold price, they can also choose to charge later according to their convenience. And, if the charging price is not quite high, they can go for charging accordingly.

But, if EV arrives with available energy less than the threshold value, then, in any case, they have to get their vehicle charged. For that particular case, a zero-sum game theory is needed so that they don't have to pay the maximum price, and CS should also get the benefit for charging based on the parameters. The zero-sum game consists of two players, P$\{\nu, \zeta, \Pi\}$ in which Π is a payoff function in the form of a matrix. EV can charge their vehicles based on the charging price assigned to the CS. But, charging prices should not be high or low to such an extent that it can lead to loss for EVs and CS.

For that, EV and CS choose the pure strategy P_s^{ν} and P_s^{ζ} to form a payoff matrix $\Pi_{(\nu,\zeta)}$. The strategy P_s^{ν} of EV aims to minimize the charging price ρ_{ζ}^{dp} and CS with the strategy P_s^{ζ} aims to maximize the charging price ρ_{ζ}^{dp}.

Therefore, both the users try their fullest to optimize the profit, which requires the discussion of payoff matrix which consists of strategies of EV and CS. Considering the payoff matrix $\Pi_{(\nu,\zeta)}(P^{\nu}_{s_1}, P^{\zeta}_{s_1})$ which consists of maximized charging price for both EV and CS. But, according to their strategy P^{ν}_{s} and P^{ζ}_{s}, i.e., EV attempt to minimize the charging price for their profit and CS already has maximized price for their profit. The above mentioned associations for $\Pi_{(\nu,\zeta)}(P^{\nu}_{s_1}, P^{\zeta}_{s_1})$ based on the strategy, maximized price, and minimized price based on the parameters can be represented as follows:

$$\rho^{dp}_{\zeta}(Max) = \{(\rho^{dp}_{\zeta}(Hp), \rho^{dp}_{\zeta}(Hp^{'}), \rho^{dp}_{\zeta}(Hp^{''}), \rho^{dp}_{\zeta}(Hp^{'''}))\} \tag{18}$$

$$\rho^{dp}_{\zeta}(Min) = \{\rho^{dp}_{\zeta}(Lp), \rho^{dp}_{\zeta}(Lp^{'}), \rho^{dp}_{\zeta}(Lp^{''}), \rho^{dp}_{\zeta}(Lp^{'''})\} \tag{19}$$

$$\nu((\Gamma_{\nu}))(\rho^{dp}_{\zeta}(Max)) \xrightarrow{\iota} \rho^{dp}_{\zeta}(Min) \tag{20}$$

Similarly, in payoff matrix $\Pi_{(\nu,\zeta)}(P^{\nu}_{s_1}, P^{\zeta}_{s_2})$ which involves maximized charging price and minimized charging price for EV and CS. Now, based on their strategy P^{ν}_{s} and P^{ζ}_{s}, in which EV mainly want to minimize the charging price for their benefit and CS want to maximize the charging price. So, the mentioned strategy for EV and CS in payoff matrix $\Pi_{(\nu,\zeta)}(P^{\nu}_{s_1}, P^{\zeta}_{s_2})$ can be defined as follows:

$$\nu((\Gamma_{\nu}))(\rho^{dp}_{\zeta}(Max)) \xrightarrow{\iota} \rho^{dp}_{\zeta}(Min) \tag{21}$$

$$\zeta(\rho^{dp}_{\zeta})(\rho^{dp}_{\zeta}(Min)) \xrightarrow{\iota} \rho^{dp}_{\zeta}(Max) \tag{22}$$

Now, for payoff matrix $\Pi_{(\nu,\zeta)}(P^{\nu}_{s_2}, P^{\zeta}_{s_1})$ which comprises of minimized charging price and maximized charging price for EV and CS, which is exactly according to their strategy for their benefits. But, if we consider the payoff matrix $\Pi_{(\nu,\zeta)}(P^{\nu}_{s_2}, P^{\zeta}_{s_2})$ which involves minimized price for both EV and CS. Now, this is in favor of EV, but CS may not get any benefit from minimized price. Therefore, based on the strategy P^{ζ}_{s}, they attempt to maximize the price to get the overall benefit. So, we can defined the above mentioned associations as follows:

$$\zeta(\rho^{dp}_{\zeta})(\rho^{dp}_{\zeta}(Min)) \xrightarrow{\iota} \rho^{dp}_{\zeta}(Max) \tag{23}$$

So, we have discussed the payoff matrix for $\Pi_{(\nu,\zeta)}$ for EV and CS based on their strategy so that they can get the maximized profit for charging. But, it is not possible to satisfy both of them. Therefore, in zero-sum game theory approach, saddle point is a condition after which users can't diverge from their strategy to get the benefit for charging. In the proposed system, saddle point can occur in payoff matrix $\Pi^{s}_{(\nu,\zeta)}$, when charging price can be considered between minimized price $\rho^{dp}_{\zeta}(Min)$ and maximized price $\rho^{dp}_{\zeta}(Max)$ to satisfy both EV and CS in terms of payoff. The payoff matrix $\Pi^{s}_{(\nu,\zeta)}$ with strategy $\{P^{\nu}_{s^*}, P^{\zeta}_{s^*}\}$ at the saddle point can be represented as follows:

$$\rho^{dp}_{\zeta}(Min) < \Pi^{s}_{(\nu,\zeta)}(P^{\nu}_{s^*}, P^{\zeta}_{s^*}) < \rho^{dp}_{\zeta}(Max) \tag{24}$$

Therefore, the zero-sum game theory approach at the saddle point optimizes the payoff for EV and CS based on the considered parameters. Algorithm 2 shows the detailed strategy to optimize the payoff of P number of players, i.e., ν, and ζ with the time complexity of O(P). The time complexity of the Algorithm 2 completely depends on the optimized payoff of the P number of players.

IV. Experimental Results of the proposed system

This section specifies the performance analysis of the proposed system, which has been implemented on Remix IDE(Integrated Development Environment). The results have been analyzed with the execution of the smart contract using solidity language. Further, the zero-sum game theory approach has been applied to optimize the payoff for users. The results for optimized payoff has been simulated in python 3.2 at a particular point, i.e., saddle point. The experimental results have been estimated based on various parameters such as latency, the optimal payoff of the system, and profit analysis for EVs. These parameters can be represented as follows:

A. Latency

Fig. 2 shows the correlation between the latency of the proposed system with 6G and traditional systems with 5G and 4G networks. It depicts that latency is aligned at the same level in the case of fewer transactions between EVs and CS. But, the increased number of transactions between EVs and CS yield improved latency for the proposed system with 6G than 4G and 5G networks. This is due to the prominent properties of 6G network, which are high data speed ($Ds_{6G} < 10Gbps$), high availability, and low-latency ($Latency_{network} < 1ms$).

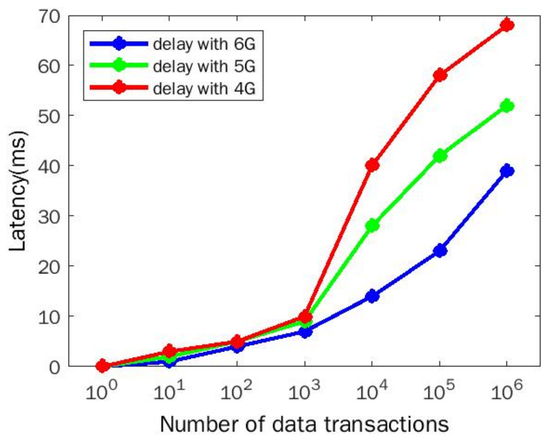

Fig. 2: Latency comparison.

B. Optimal payoff of the system

Fig. 3 shows the optimal payoff of the proposed system with the rise in the number of transactions between EVs and CS. The graph depicts that as the number of data transactions between EVs and CS increases, the payoff of the proposed system tends to converge optimally up to a particular point. This is due to the applied zero-sum game theory approach to optimize the payoff for users in which there exists a saddle point. At this point, the optimized payoff is determined with the help of the average of maximized charging price and minimized charging price based on the various parameters. The existence of saddle point denotes that, after this point, users can't alter their strategy. So, the graph reflects the stability after the saddle point, further optimizing the payoff for EVs and CSs.

C. Profit for EVs and CS

Fig. 4 depicts the correlation between profit for EVs and profit for CS based on the increase in the number of data transactions. It can be distinguished from the graph that profit

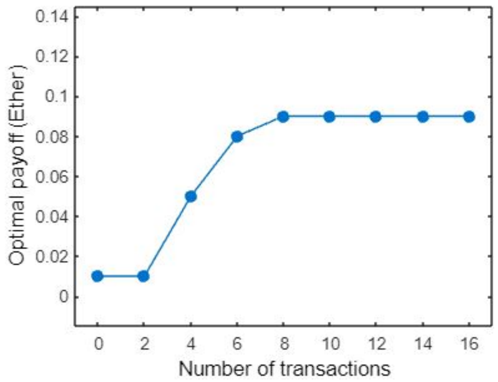

Fig. 3: Optimal payoff of the system.

for EVs and profit for CS increases linearly with the rise in the number of transactions. But, profit for both of them tends to be stable and optimal after a certain point, i.e., saddle point based on the zero-sum game theory. It can also be observed from the graph that the profit for EVs is less than the profit for CS. CS can profit from multiple EVs arriving for charging, but EV gets a benefit for their charging only. Therefore, profit for CS is somewhat high than profit for EVs.

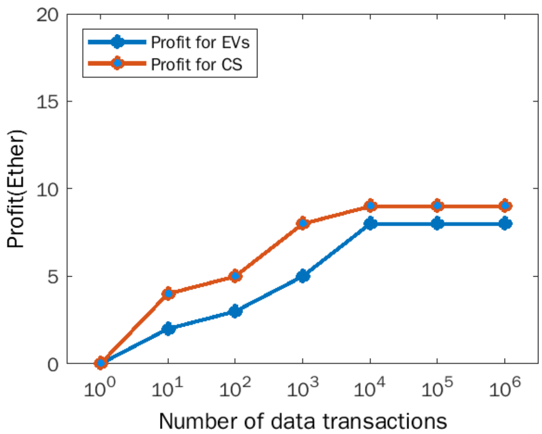

Fig. 4: Profit analysis.

V. Conclusion

This paper proposes a blockchain integrated with IPFS -based secure dynamic pricing scheme for EVs charging over the 6G communication network. We have analyzed the blockchain-based traditional schemes to get insights into their security, profit, latency, and cost-efficiency issues. Introducing the 6G network with decentralized and cost-efficient IPFS data storage protocol ensures high efficiency and reliability in the system. We have formulated a zero-sum game theory approach to optimize the payoff for EVs and CS with the existence of a saddle point to make the system profitable and accessible. The proposed system has been implemented on Remix IDE using the solidity programming language. Finally, the proposed system has been evaluated based on the parameters such as latency, profit for EVs, profit for CS, and overall optimal payoff of the system. The analysis of the results shows that the proposed system outperforms the traditional systems in terms of cost-efficiency, profitability, low latency, and high reliability.

In the future, we will explore more about the scenario in which the multiple number of EVs and CSs can be considered to optimize the payoff using a game theory approach to ensure the dynamic capability of the proposed system.

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