New Challenges of Wireless Power Transfer and Secured Billing for Internet of Electric Vehicles

Laihyuk Park, Seohyeon Jeong, Demeke Shumeye Lakew, Joongheon Kim, and Sungrae Cho

***Abstract*—Smart grid modernization and integration of IoEVs have attracted much attention due to their processing capability and convenience. In addition, the developments of magnetic resonance or inductive-based WPT technologies can improve the efficiency of power transmission and user convenience. Especially, the use of RERs is very attractive for low-carbon clean energy, and thus we can imagine integration services that utilize RERs and IoEVs. Accordingly, energy trading markets among IoEVs and power stations will appear in future smart grids. Thus, this article proposes an auction mechanism for energy trading markets of IoEV and RER power stations. Moreover, we can imagine a convenient system where IoEVs can automatically be charged from the WPT charging pad when they are parked in an IoEV parking lot. However, to realize such a convenient system, there are several problems that need to be resolved. Suppose that many IoEVs are parked in the parking lot; then due to power system constraints, it is impossible to simultaneously charge all IoEVs at maximum power. Therefore, an efficient load scheduling algorithm that allows several EVSEs to charge many IoEVs is required. Furthermore, when IoEVs are automatically charged in the anticipated convenient system, it is particularly challenging to design a suitable and secured billing system. In this article, we introduce the advantages of a convenient system that integrates IoEVs and a smart grid. Moreover, we discuss the challenges and solutions for future charging and billing systems.**

***Index Terms*—Internet of Electric Vehicle, IoEV, Wireless Power Transfer, WPT, auction, block-chain.**

TABLE I: Acronyms in IoEVs

Acronyms	Descriptions
3GPP	3rd generation partnership project
D2D	Device-to-device
DEVC	Dynamic electric vehicle charging
DoD	Depth of discharge
eNB	Evolved Node B
ESS	Energy storage system
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
IoEV	Internet of electric vehicle
ITS	Intelligent transportation system
OLEV	Online electric vehicle
PHEV	Plug-in hybrid electric vehicle
RER	Renewable energy resource
RF	Radio frequency
SoC	State of charging
V2I	Vehicle to infrastructure
V2X	Vehicle to everything
WAVE	Wireless access for vehicular environments
WEVC	Wireless electric vehicle charging
WPT	Wireless power transfer

I. Introduction

In recent years, EVs[1] have evolved into IoEVs, which can support V2X and V2I communication protocols such as WAVE [1] or 3GPP-V2X [2]. Inconveniences and safety issues in wet environments for conventional wired IoEV charging methods impede the widespread proliferation of IoEVs. Moreover, the electricity loss, which occurs at the connector of the wired IoEV charger, should not be ignored. In order to solve the above problems of wired IoEV charging systems, WPT technologies such as Qualcomm Halo have recently been developed and their commercialization is approaching [3].

This article introduces user-friendly applications that combine these technologies. Fig. 1 shows the proposed future charging and billing systems for IoEVs. In future smart grid systems, the use of RERs such as photovoltaic or wind turbine resources will be more prominent. Accordingly, we can imagine an RER power station of IoEVs. In general, the real-time electricity price from RER can vary depending on the amount of electricity stored in the ESSs [4]. These pose a challenge for the users to know the real-time pricing at the RER power stations. However, in the IoEV environment, users recognize prices in real-time, thus there will be an IoEV energy trading market in which the user occupies the electricity of the RER power station via the Internet. In the proposed energy trading market, the amount of electricity from RER is limited and buyers will compete the electricity for their profit. Therefore, the auction based energy trading market can emerge. For the IoEV energy trading market, this article assumes IoEVs and RER power stations to be buyers and sellers, respectively, and proposes appropriate auction algorithms. In addition to the above application, an automatic charging system in a parking lot can be also imagined. EVSEs have been installed in most of the current building parking lots, and the WPT pad is expected to be installed in future building parking lots. Therefore, it is possible to imagine a system in which an IoEV is automatically charged when the user parks on the WPT pad. Due to power supply limitations of the buildings, however, it is impossible for all WPT pads to simultaneously charge all IoEVs. To solve this charging problem, this article proposes a WPT charging scheduling algorithm. Moreover, in

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[1]All acronyms are defined in Table I.

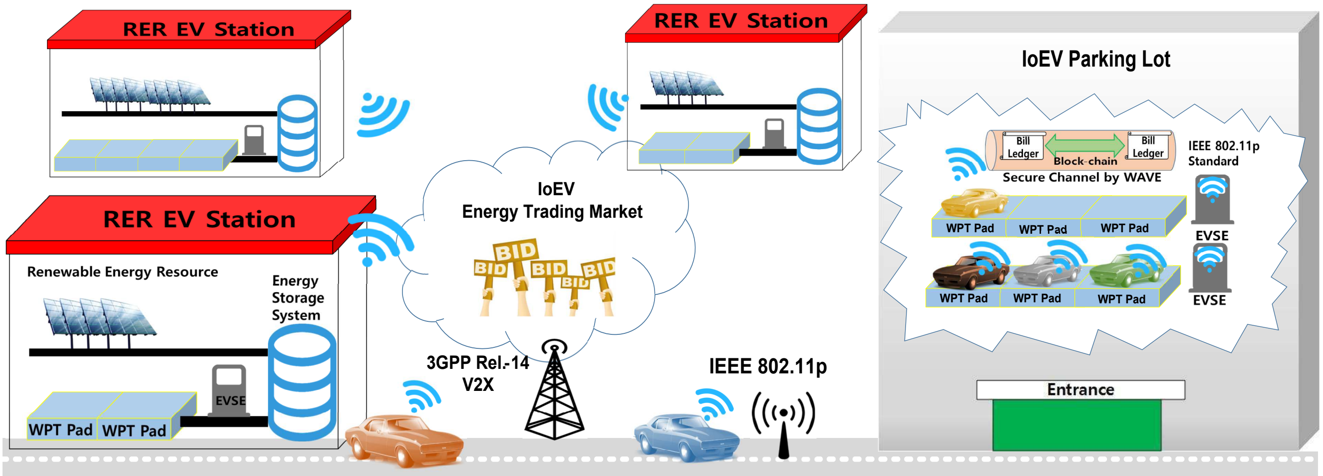

Fig. 1: The proposed architecture of the convenient system. (In the proposed system, IoEV automatically charges the electricity via WPT. Billing is securely charged through block-chain and WAVE technologies).

the current billing system, users make payments directly from the EVSE. However, these systems are not only inconvenient, but also have limitations in terms of their vulnerability to risks such as EVSE cheating. Thus, to solve this problem, this article proposes a block-chain-based secured billing algorithm. The block-chain technology presents a way for players to agree on specific state of matters and record that consensuses in a secure and confirmable manner by integrating various technologies such as peer-to-peer networks, distributed data storage, cryptographic algorithms, and decentralized consensus technique. Therefore, the proposed secured billing system is constructed based on the block-chain technologies. Since the proposed secured billing algorithm agrees to a contract only if the conditions of the IoEV and EVSE are met, it is thus trustful. In addition, convenience will be improved since contracts are automatically made without user involvement.

The rest of this article is organized as follows. In Section II, the background technologies of WPT and IoEV are described. Section III introduces the energy trading market for the RER power station and presents the auction algorithm for the energy trading market. The challenges of automatic IoEV charging systems in future parking lot as well as the proposed IoEV charging and block-chain-based secured billing algorithms are presented in Section IV. Finally, Section V concludes the article and suggests future directions.

II. Background

A. Wireless Power Transfer for IoEV

WPT technology is attracting considerable interest for charging IoEVs because of its convenience, safety, and better user experience compared to the conventional wired charging system. This is due to the fact that charging IoEVs using conventional wired charging methods such as PHEVs are inconvenient since a user has to connect the charging cable directly from the EVSE to the IoEV. However, using a wirless power charging method is convenient since the IoEV can be charged immediately when parked in a space where a WPT pad is installed. Furthermore, in WPT, the range of electric buses and light rail vehicles can be extended through either dynamic opportunity charging while moving or during station stops [5].

In recent years, research on WPT for IoEVs has been actively conducted. Accordingly, WPT methods can be classified into three types: RF charging, inductive charging, and magnetic resonance charging [6]. The characteristics of each WPT charging method are described in Table II.

Due to the transmission efficiency and the effects on the human body, charging methods based on inductive charging and magnetic resonance are more advantageous than RF charging methods. However, inductive charging is not susitable for the IoEV charging since its charging distance is very short. Therefore, research on WPT for IoEVs is mainly investigated considering magnetic resonance charging methods.

In 2009, KAIST (Korean advanced institute of science and technology) research university in Daejoen, South Korea, developed OLEV green design concept to power electric vehicles wirelessly through a shaped magnetic field in resonance [8]. OLEV buses and infrastructure are operating both at the KAIST Daejoen campus test site and in Gumi, South Korea. OLEV is designed to receive up to 100 kW of power with 85 percent transmission efficiency over a fixed air gap of 20 cm. Qualcomm Halo WEVC is a highly efficient, convenient and easy-to-use wireless charging technology for charging IoEVs. Drivers of Halo vehicles simply park and charge without the need for plug-in cables or adaptors. The technology for Halo vehicles has been developed over many years. Working closely with the automotive industry, this technology uses resonant magnetic induction to transfer energy wirelessly from a ground-based pad to a pad integrated in the vehicle. Quick charging is possible with high power WEVC, supporting wireless power transfers at 3.7 kW, 7.4 kW, 11 kW, and 22 kW with a single primary base pad and wireless power transfer efficiency of $>$ 90 percent. In addition, Qualcomm has tried to develop DEVC, which allows vehicles to charge while driving, based on the Halo WEVC system. The DEVC system aims to be capable of charging the IoEV dynamically at up to 20 kW

TABLE II: WPT Methods

	RF Charging	Inductive Charging	Magnetic Resonance Charging
Mechanism	RF charging uses radio frequencies to charge an electronic device and its operating frequency varies from 300MHz to 300GHz [7].	This approach charges a device using the magnetic field induction phenomena between the coils and operates in the KHz frequency range [7].	This method charges a device using the magnetic resonance between the transmitter and receiver antennas and operates in the MHz frequency range [7].
Charging Distance and Efficiency	The RF charging method can transmit up to several tens of km. However, the power charging efficiency is about 1–10 percent.	The inductive charging method exhibits more than 90 percent power efficiency within 4cm.	The power efficiency of this method is 90 percent at 1m and 40 percent at 2m.
Characteristics	Transmitting power for actual charging can cause harm to the human body.	It is harmless to the human body. It is widely used for mobile phone charging since its transmission efficiency is high at short distances.	This charging method is harmless to the human body. For high transmission efficiency of the magnetic resonance, a significantly large charging module is required.

at highway speeds [9].

B. Internet of Electric Vehicles Technologies

IoEV communication technologies enable EVs to be connected to the Internet, while improving driving stability and efficiency through communication with other vehicles, drivers, and infrastructure. For reliable and efficient transition from EVs to IoEVs, standardized wireless communication technologies are required. The standardization of IoEV technologies can be classified into 1) *WAVE* based on IEEE (Institute of electrical and electronics engineers) 802.11p [1], [10] and 2) *3GPP Rel.14–V2X* based on LTE (Long term evolution) [2].

1) WAVE technologies: The WAVE protocol is designed to support ITSs in short-range vehicular communications [10]. The WAVE protocol stack is designed based on the IEEE 802.11p and IEEE 1609 standards. The IEEE 802.11p standard is an approved amendment to the IEEE 802.11 standard to add WAVE. It is designed based on the conventional IEEE 802.11 standards with several modifications to support vehicular-based communication networks. Its physical layer is designed based on the IEEE 802.11a standard with a reduction of the bandwidth, and thus can handle highly mobile environments. Its MAC (Medium access control) layer is inspired by the IEEE 802.11e standard. The MAC layer supports enhanced distributed channel access, which allows quality-of-service based scheduling. The WAVE MAC layer supports IEEE 1609.4 in addition to IEEE 802.11p. IEEE 1609.4 supports multi-channel operations and timing advertisement frames for the vehicular environments, and IEEE 1609 provides communications security and authentication capabilities for the packets. IEEE 1609.3 supports the networking services such as system addresses and routing management. Therefore, IoEV can use the Internet by connecting to the WAVE roadside unit.

2) 3GPP Rel.14–V2X: The initial Cellular V2X protocol stack, for inclusion in the 3GPP Release 14, was standardized in March 2017. The 3GPP Rel.14–V2X is designed based on the 3GPP Rel.12-D2D protocol by considering vehicular environments. The main difference from 3GPP Rel.12-D2D is that additional synchronization signals are required, and this stack synchronizes via a global navigation satellite system from the satellite as well as a sidelink synchronization signal from eNB [2]. Moreover, 3GPP Rel.12-D2D considers time division multiplexing, whereas 3GPP Rel.14–V2X considers frequency division multiplexing. In order to consider traffic congestion situations, a detection method for short distances between vehicles within the same channel is introduced. Therefore, the IoEV connects to the Internet via the 3GPP Rel.14–V2X technique.

These communication technologies and standards help to establish an energy trading market within IoEVs and RER power stations as well as an automatic IoEV charging system.

III. Energy Trading Market for a Renewable Energy Resource Power Station

As discussed in Section I, RER power stations will appear in future smart grid systems. The RER power station is responsible for selling the electricity from RERs to IoEVs. However, integration of RER with IoEVs has several challenges. The electricity from RER is unpredictable and intermittent since electricity production can be significantly higher or lower than the demand depending on the available energy resources. This problem can be solved by adopting ESSs that can balance the electricity generation from RERs [11]. ESSs absorb or supply electricity in the case of excess and low power generation, respectively [12]. Therefore, this article assumes that the RER power stations include ESSs. The electricity price from the RER can be determined depending on the RER types [13] and the remaining electricity amount of ESSs [4]. Therefore, all RER power stations will have different electricity prices, and the price can be changed according to the station situation. In future IoEV environments, however, the RER power station can expose the electricity price and amount of electricity via

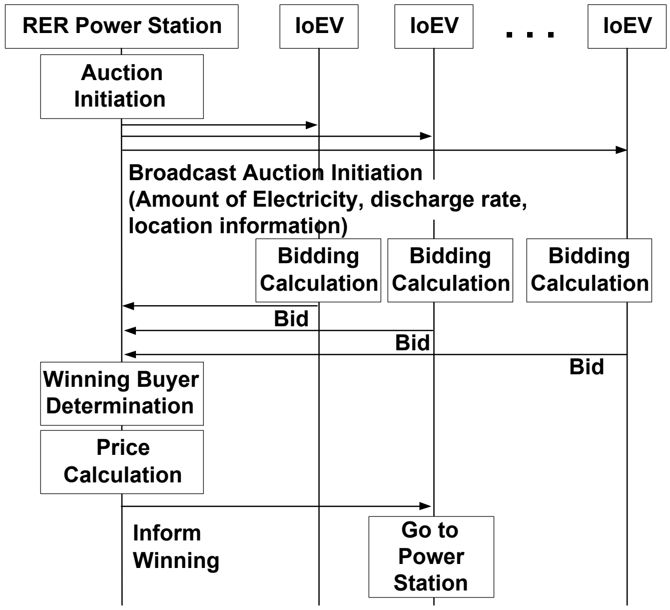

Fig. 2: Sequence diagram of the proposed auction mechanism.

the Internet, and IoEVs can purchase the electricity in advance. This article proposes the energy trading algorithm for IoEV and RER power station markets. The proposed energy trading algorithm implements a greedy second price auction. The second price auction, which is one of most popular auction algorithms in real-world scenarios, determines the winning bidder who submitted the first highest bid and the price as the second highest bid. The second price auction is, in principle, a sealed bid to determine the price[2]. In the proposed auction, the RER power station is a seller who wants to sell electric power, and an IoEV who wants to buy electric power is a buyer. The RER power station can determine the amount and price of electricity to sell. Since the RER power station discharges as time passes, the winning buyer and the price should be determined considering the estimated electrical energy to be discharged according to the distance to the IoEV. Fig. 2 shows the proposed auction mechanism. As shown in the figure, the proposed auction consists of 1) auction initiation, 2) winning buyer determination, and 3) price calculation. The details of each step are described as follows.

1) Auction initiation: The RER power station broadcasts a message containing the total amount of electricity E that it wants to sell, the rate of discharge per hour, and its location information. The IoEV calculates a bid b according to the expected value that reflects the desired amount of charge and the amount of discharge l (which is predicted to occur during the movement time using its location and location information of the RER power station). Then, the IoEV secretly submits the bid b and the required amount of electric power d to be charged containing discharge l.
2) Winning buyer determination: The RER power station can treat the bid B as the price per watt by dividing b by d. In the proposed auction, the IoEV that submitted the highest B is determined as the winning buyer, and then the next winning buyer is determined using its remaining chargeable amount $E = E - d$. The next winning buyer determination is calculated among the IoEVs with $E \geq d$, and the process is the same as above. The recursive process is repeated until the remaining E cannot cover any remaining d.
3) Price calculation: The price is calculated when a winning buyer is decided. For the second price auction, the price is determined using the highest bid as B' among the bids except the winning buyer's bid. Since the amount of electricity required to charge the winning buyer is d, the price P can be calculated as $d \cdot B'$.

Since the proposed auction is an incomplete information game, the RER power station secretly informs the winning buyer about the determined price.

For example, suppose there are 50 kWh remaining in an ESS at the RER power station (e.g., E), and 5 IoEVs intending to charge 10 kWh, 5 kWh, 4 kWh, 3 kWh, and 1 kWh, respectively. The 5 IoEVs are located at different distances from the RER power station and thus take different amount of time to get to the RER power station. Considering the arrival time, it is assumed that the required ds at the RER power station are 11 kWh, 6 kWh, 4.5 kWh, 5 kWh, and 2 kWh, respectively. The IoEVs secretly submit b 80 cents, 35 cents, 50 cents, 30 cents, and 2 cents and d to the RER power station, respectively. Then the RER power station calculates B for each IoEV as 7.3, 5.8, 11.1, 6, and 1, respectively. The highest B is the third IoEV's B, which is 11.1, and the required amount of energy at the RER power station is 4.5 kWh. Then E is changed to 45.5 kWh and the price of the third IoEV's charge is 32.85 cents $(7.3 \cdot 4.5)$ since the second highest B' is 7.3. Then the RER power station continues the determination of the winning buyer and calculate the price with the remaining E and Bs.

Generally, auction discussions focus on truthfulness, individual rationality, and a balanced budget [14].

- Truthfulness: The bidder submits the bid with the true valuation of the item.
- Individual rationality: When the expected utility of all participants is positive, the auction is the individual rationality.
- Balanced budget: When the buyer's payment is transferred to the seller without any exchanges at the auction, it is budget balanced.

In the proposed auction, the buyer submits the expected price as a bid when charging the power. At this time, the true valuation of the power that is generated at the RER power station is the power generation cost of the RER power station. However, the value to be evaluated by the IoEV can be different depending on the distance to the RER power station or the amount of energy remaining in its battery. Therefore, it

[2]In contrast with a second price auction, a first price auction determines the price with the highest bid. A first price auction will be good for the seller since the benefit of the seller is larger than the benefit of the second price auction. However, this article assumes that electricity is a quasi-public good. Therefore, this article proposes a second price auction, which determines a more rational price than the first price auction.

is difficult to accurately predict the true value of the power at an IoEV, and thus the proposed auction may not be truthful.

If the winning buyer's *utility* is defined as $bid - price$, each price paid by the winning buyer is less than their bid, since this is a second price auction. Thus, the expected utilities of all buyers are positive, and thus the proposed auction has individual rationality.

In this auction, an auctioneer that mediates the auction is not required, and the seller decides the payment to the auction scheme. Therefore, there are no additional fees incurred from intermediate commissions or the auction process. Also, the auction is budget balanced since the buyer has to transfer the payment to the seller as determined by the seller. In order to avoid cheating the price, an RER station should be authorized in the energy trading market.

In the proposed system, abnormal situations may occur. For instance, IoEV may leaves the parking lot before its battery has been charged with the agreed amount of energy. At this time, it is necessary to determine the charging bill accordingly. In addition, there should be a procedure in case of system failure. Handling these and other possible abnormal situations are left as future research work.

IV. Automatic IoEV Charging System in a Parking Lot

Before describing more details of the proposed automatic IoEV charging system in parking lots, we first present some assumptions. First, we assume that all parking spaces have installed a WPT pad. The second assumption is that EVSEs support the WAVE protocol since WAVE is one of the most successfully deployed solutions in the research society[3].

Fig. 3 shows the sequence diagram of the proposed automatic IoEV charging system and the considered scenarios are described as follows:

1) Automatic Authentication: When an IoEV is parked in the parking lot, it will automatically detect the EVSE and then an authentication to the EVSE will be carried out via the IEEE 802.11p protocol. Since both the IoEV and EVSE support the WAVE standard, a secured communication channel is established through the IEEE 1609 standard.
2) Exchange pre-contractual Information: After authentication, the IoEV will be charged via the WPT pad without user operation. Of course, user preferences such as the electricity amount or the electricity bill can be set for the IoEVs. First the EVSE is informed of the electricity pricing. Based on the user preference and the electricity pricing, the IoEV determines whether to charge or not. If the IoEV decides to be charged, it sends the maximum charging amount and its payment information.
3) IoEV Charging: All IoEVs cannot be charged simultaneously due to the power supply limitations of the building. Therefore, the EVSE should schedule the IoEV charging.

[3]Since our argument in this article is scalable, we can assume the other local/personal area network solutions such as bluetooth, Wi-Fi, etc.

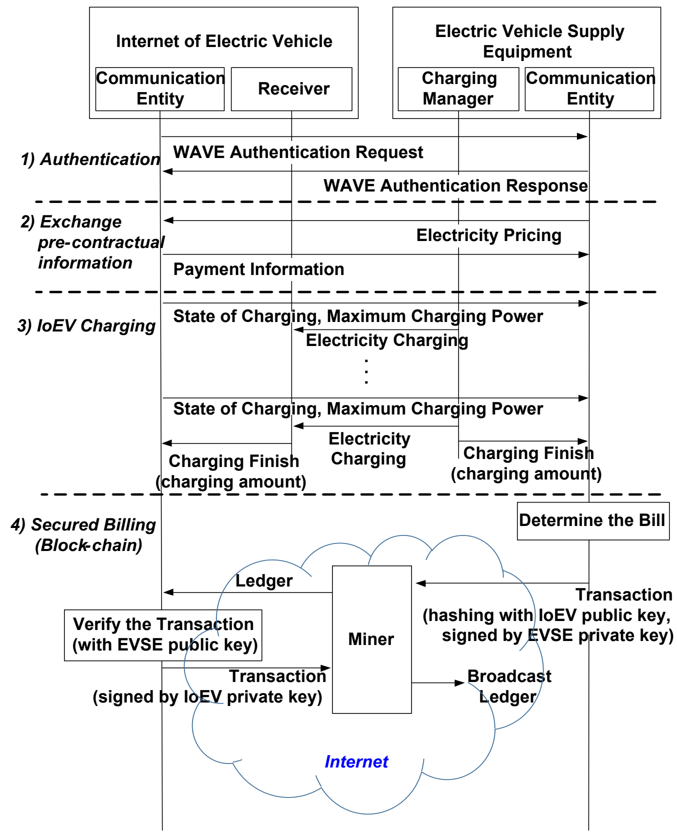

Fig. 3: Sequence diagram of the proposed automatic IoVE charging system.

4) Secured Billing: After charging, an IoEV should pay the electricity bill. Generally, EVSEs price the electricity bill based on their smart meters. At this time, an EVSE can cheat the pricing of the charging. To solve this problem, the IoEV should check the charging amount in the proposed algorithm. Through block-chain technology, the ledger will be valid if both the IoEV and EVSE contracts are met. Since both the IoEV and EVSE are connected to Internet, the proposed algorithm is operated when they are not directly associated, i.e., although the IoEV moves out of the parking lot before payment is completed, the secured billing will be executed via the Internet.

In the proposed system, scenario steps 1) and 2) will be solved by the WAVE protocol. However, the IoEV charging scheduling and secured billing have several challenges to solve. In the following subsections, we proposed solutions to solve the challenges.

A. IoEV Charging Scheduling

Consider an IoEV parking lot where multiple IoEVs and charging pads coexist. In this case, it is impossible to assume that all IoEVs are charged with maximum power at the same time due to power supply limitations. Fig. 4 (a) shows the electric PHEV charging system that is currently installed in a commercial building parking lot. As shown in the figure, multiple PHEVs are sharing a single EVSE since there is

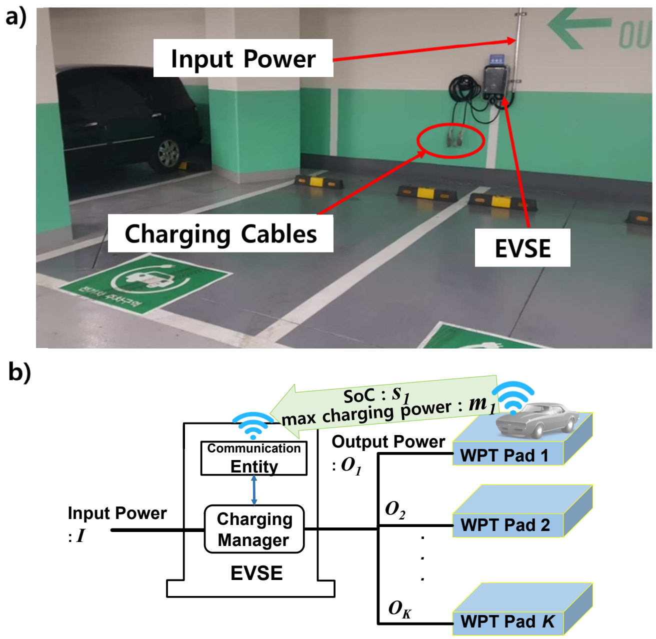

Fig. 4: WPT charging system for an M to M environment. a) PHEV charging system in Chung-Ang University, Building 310. A single EVSE charges multiple PHEVs. b) The proposed IoEV parking lot. Due to power system limitations, a single EVSE will manage multiple IoEVs.

a limited amount of power that can be used for PHEVs in buildings. Based on this concept, the proposed IoEV charging system is described, as shown in Fig. 4 (b). As depicted in the figure, a single EVSE is charging multiple IoEVs. Before describing the details of the load scheduling, the following assumptions are desired. The time is divided into equivalent timeslots t. A single EVSE manages K IoEVs at time t. The input power of EVSE is modeled by I. In every timeslot t, an IoEV provides information on its SoC s_k^t, where the current fuel gage of the battery pack and unit of SoC are represented as percentage points (0 =empty, 100 =full), and m_k is the maximum charging power of the EVSE via the WAVE protocol. Therefore, the DoD d_k^t, which is the required electricity of IoEV k, is $(100 - s_k^t)$. This article assumes that the EVSE determines the energy efficiency ec_k by measuring the current SoCs and output power O_k^t, and ec_k is calculated by $(s_k^{t-1} - s_k^{t-2})/O_k^{t-1}$. Based on the information, the charging manager decides O_k^t for all WPT pads ($O_k^t \leq m_k$). This article introduces simple load scheduling algorithms according to an EVSE policy as follows:

- **Fairness Scheduling:** Suppose the EVSE believes that an IoEV should be fairly charged over time, i.e., a longer parked IoEV charges more electricity. Therefore, a simple round robin scheduling approach can be considered. At time t, O_k^t is calculated as $\max(I/K, m_k)$.
- **Battery Stability Scheduling:** Suppose the EVSE considers the IoEV battery stability. Since each IoEV requires a different amount of electricity, charging the same amount of electricity to all IoEVs makes the state of the battery unstable. For example, the SoC of IoEVs i and j are charged 20 percent and 80 percent, respectively. For the battery stability, IoEV i needs more electricity than IoEV j. Therefore, a simple proportional fairness scheduling approach can be considered. At time t, where O_k^t is obtained as $\max(I \cdot d_k^t / \sum_{i \in K} d_i^t, m_k)$.
- **Energy Efficiency Scheduling:** The charging efficiency of each IoEV may be different due to the position on the pad or the receiver performance. Charging the IoEV with lower charging efficiency leads to a waste of energy. For energy efficient load scheduling, a simple greedy scheduling algorithm can be considered. In the proposed scheduling algorithm, the EVSE sorts the ec_k and then sequentially allocates the maximum output power m_k according to descending order, i.e., an IoEV with a lower SoC will be charged earlier.
- **Energy Efficiency and Battery Stable Scheduling:** Considering both battery stability and energy efficiency, s_k^t can be used to model the battery stability, i.e., an IoEV with a higher SoC is more stable. The optimization problem can be designed to allocate more electricity to the IoEV with a lower battery stability and higher charging efficiency. Therefore, the objective function, which can find optimal O_k^t, is designed to maximize the sum of ec_k and minimize the sum of s_k^t. Since ec_k and s_k^t are constant values, the objective function can be convex.

The introduced algorithms perform load scheduling in real time. Therefore, they are suitable for an IoEV parking lot environment where the arrival and departure processes of the IoEVs are not predictable.

B. Secured Billing by Block-chain

Recently, block-chain technologies have been popularly researched due to their security and convenience benefits, i.e., cryptocurrency provides a convenient billing layer and has paved the way for a marketplace of services [15].

Therefore, this article applied such block-chain techniques to the IoEV charging and billing systems. The proposed secured billing algorithm will be applied to the energy trading market as discussed in Section III.

The proposed secured billing system consists of IoEV nodes, EVSE nodes, and miner nodes. The miners are responsible for periodically generating blocks. This article assumes the miners are public institutions for electric supply and management, such as Korea Electric Power Cooperation. In this article, therefore, the miners are also responsible for finding untrustful nodes, i.e., cheating IoEVs and EVSEs can be reported to the miners in the proposed system.

Since IoEVs are charged based on a schedule and may unexpectedly move out of the parking lot, the charge amount would not be known before charging is complete. Therefore, the EVSE will price the electricity bill after IoEV charging is complete. The block-chain-based secured billing is performed as follows:

1) **EVSE $\Rightarrow$ Miner:** After charging is complete, the EVSE receives the charging amount from the charger. Based

on the charging amount and the electricity pricing, the EVSE determines the electricity bill. Then, the EVSE creates a transaction for the electricity bill, where the transaction includes the payment information of the IoEV. The transaction is hashed with an IoEV public key. Therefore, only the corresponding IoEV approves the transaction, and private information such as payment information will be secured. In addition, the hashed transaction is signed by an EVSE private key, and thus its trust will be guaranteed. Then, the EVSE sends the signed transaction to the miner.

2) **Miner ⇒ IoEV and Internet:** The miner verifies the transaction with the EVSE public key. If the transaction is verified, the miner create a ledger with the transaction and then broadcasts the ledger. Therefore, the EVSE receives the ledger from the Internet.
3) **IoEV ⇒ Miner:** When the IoEV receives the corresponding ledger, it can assure the hashed transaction with its private key. At this time, the IoEV can expect an electricity bill based on the charging amount of its receiver. If the electricity bill in the ledger is not correct, the IoEV sends an alarm to notify the miner. Thus, the proposed scheme can prevent EVSE cheating. If the electricity bill and payment information is correct, the IoEV creates a transaction based on the receive transaction and then signs it with its private key. Then, the IoEV sends the new transaction to a miner.
4) **Miner ⇒ Financial Company and Internet:** If the miner does not receive any alarm or new transaction from the IoEV in a certain time frame, it determines that the IoEV left without paying. Therefore, the proposed scheme guarantees secured billing. When, the miner receives a new transaction, it verifies the transaction with the IoEV public key. If the transaction is verified, the miner creates a ledger with the transaction and then broadcasts the ledger. Therefore, the financial company receives the ledger, which includes payment information and the electricity bill. The financial company verifies the ledger with the public keys of the IoEV and EVSE, and then the payment is complete.

V. Conclusions and Future Work

In the near future, IoEVs will become very popular and the market will grow accordingly. In addition, smart grid networks such as renewable energy resources will be developed together. Therefore, the convergence of IoEVs and smart grids via the Internet will create new user-friendly applications. This article introduces novel applications for IoEV charging and secured billing. Based on the proposed systems, the detailed techniques will be developed in the future. The proposed energy trading market is a good technique for combining IoEVs and renewable energy resources. Based on the proposed trading system, future research will cover a route guidance system for the IoEVs. The proposed automatic IoEV charging system can maximize the user conveniences in the parking lot. Especially, the proposed block-chain-based billing system will promise a secure and convenient payment service in the charging system and will be applied in various industry applications. For the automatic charging system, there are opportunities to integrate such methods with other techniques such as artificial intelligence. For example, estimation of the parking time from the learning algorithm will improve the load scheduling algorithms.

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