Towards Reservation-based E-Mobility Service via Hybrid of V2V and G2V Charging Modes

Shuohan Liu[a], Yue Cao[b,*], Qiang Ni[a], Lexi Xu[c], Yongdong Zhu[d,*], Xin Zhang[e]

[a]*School of Computing and Communications, Lancaster University, UK*
[b]*School of Cyber Science and Engineering, Wuhan University, Wuhan 430072, China*
[c]*China Unicom Research Institute, China*
[d]*Institution of Intelligent System, Zhejiang Lab, Hangzhou 311000, China*
[e]*Electronic and Electrical Engineering, Brunel University London, UK*

Abstract

Due to the growing greenhouse effect, reducing greenhouse gas emissions is becoming increasingly important. Electric Vehicles (EVs), thanks to their lower carbon footprint, therefore are seen as the mainstream transportation of the future. However, single charging mode cannot accommodate a large number of parallel EV charging requests with limited charging infrastructures. To guarantee the Quality of Experience (QoE) of the charging service, this paper proposes a hybrid charging management scheme, by facilitating stable and fast charging from plug-in charging and flexible charging from V2V charging. Here, an optimization objective, charging cost is introduced as an optimization indicator. It considers charging price, charging waiting time and charging energy, to jointly optimize EV charging in price-time-energy dimensions. Each influencing factor is assigned a value through the Analytic Hierarchy Process (AHP) to identify its importance for EV charging. Meanwhile, due to the high mobility of EVs, charging reservation (including arrival time, required energy) is introduced, to optimize the charging selection with accurate information. Simulation results based on the Helsinki road topology show that the proposed scheme flexibly utilizes both charging modes and guarantees QoE for EV charging, in terms of increasing average

---

[*] Corresponding author

Email addresses: `871441562@qq.com` (Yue Cao), `zhuyd@zhejianglab.com` (Yongdong Zhu)

charging energy and reducing charging price and charging waiting time.

Keywords: Electric Vehicle, Hybrid Charging, EV Charging Optimization, Charging Cost.

1. Introduction

Technological changes in the field of transportation and energy are transforming people's daily mobility. In recent years, Electric Vehicles (EVs) are becoming increasingly popular. As the main source energy for EVs is electricity, EVs ensure lower pollution emissions and effectively mitigate the increased greenhouse effect. Due to the limited capacity of battery, EVs need to be charged frequently to replenish their driving range. However, the convenience of EV charging is limited by charging technology and deployment of Charging Stations (CSs). Both problems lead to charging service congestion due to service ability exhaustion of charging infrastructures, which degrades the travel experience of EV drivers and also delays the large-scale adoption of EVs.

Most of literature focuses on EV charging optimization under Grid-to-Vehicle (G2V) mode, where EVs are parked at CSs equipped with charging slots to provide parallel charging services. Here, the plug-in charging mode is widely applied, including in public transportation and most private travelling services. Optimization under plug-in charging mode focuses on charging scheduling [1] (EVs been parked at CSs) and CS-Selection [2] (EVs on-the-move), corresponding to "when-to-charge" in the time domain and "where-to-charge" in the spatial domain respectively. Nevertheless, limited by rigid location and under-deployed density of CSs, the plug-in charging mode can not provide time-spatial flexibility. In addition, the plug-in charging mode also faces the problem of rigid CS deployment and high CS operation cost in price domain [3].

With the development of battery technology, Vehicle-to-Vehicle (V2V) charging mode has been proposed as an alternative [4]. It allows energy transfer from an EV with energy supply, to an EV with energy requirements. Here, Parking Lots (PLs) are repurposed as places for V2V charging by deploying DC-DC converters, to escape from the rigid deployment of CSs [5]. Through the converters available at PLs, EVs as energy Providers (EV-P) transfer surplus energy to EVs as energy Consumers (EV-C) in the form of Vehicle-to-Vehicle charging Pair (V2V-Pair). Here, the V2V charging mode acts as an auxiliary mode to the plug-in charging mode, which balances the load of grid, and reduces charging congestion for EVs during peak charging hours. The fundamental optimization objective under the V2V charging mode are V2V-Pair matching (maximizes charging utility) and PL-Selection (minimize charging waiting time). Nevertheless, the V2V charging mode suffers from challenges including long charging time (low charging power via converters [6]), high transmission energy loss [7] and uncertain energy supply [8].

The shortcomings of plug-in and V2V charging modes limit further user Quality of Experience (QoE) enhancements. Thus, a hybrid charging management is proposed to flexibly utilise the advantages of both charging modes [9]. However, above two charging modes differ in their application scenarios. The plug-in charging mode is used for deterministic charging as the charging place is fixed and public, while V2V charging is used for opportunistic charging as the charging place is flexible and uncertain [10, 11]. It is crucial to figure out how to combine the advantages of V2V charging (high flexibility) and plug-in charging (high stability). Although the plug-in charging is stable and fast [12], the deployment of CS is costly and rigid in location, this still leads to higher electricity price and longer charging waiting time. The V2V charging mode is flexible in terms of location [13], however with limitation in slow charging power and uncertain energy supply from EV-Ps.

With vision to integrate both charging modes into sustainable eco-system for future smart city, we propose a hybrid charging management in this paper. The proposed management recommends the most suitable charging mode (CS/PL-Selection) with aim to minimize charging cost for EV. The charging cost is calculated with consideration of charging price, charging waiting time (time spent from arrival at CS/PL to the start of charging service) and charging energy factors. Our contributions are as follows. Technically:

1. *Hybrid plug-in & V2V charging management framework:* In previous works, EV charging optimization has been solely considered under a single charging mode (those [13, 14] under V2V charging and that [15] under plug-in charging). Although, some literature applied V2V charging as a replacing of grid when the grid stops supplying energy ([8, 16, 17]). We propose a hybrid charging management in this paper, which allows EV charging via two different charging modes. This framework alleviates charging congestion and flexibly utilizes heterogeneous charging infrastructures across city.
2. *Collaborative optimization in price-time-energy dimensions:* In this paper, we propose a charging cost optimization function, which is jointly calculated by expected charging price, charging waiting time and charging energy (price-time-energy dimensions). Here, the weights of each dimension are innovatively assigned based on the Analytic Hierarchy

Process (AHP). By selecting the charging service with the lowest charging cost, EV charging can be optimized across above three dimensions.

3. *Hybrid real-time recommendation system:* Unlike previous literature that utilized offline data (historical price data [6], fixed energy requirement [18]), real-time data is considered in this paper. Real-time data better represents complexities of the real-world conditions, but changes in real-time data are more difficult to predict. We therefore introduce charging reservation, including EV arrival time and expected charging energy, to effectively alleviate this problem and improve the charging recommendation by accurate information.

In Section II we provide a brief review on related works, followed by Section III in which the preliminary is elucidated. In SectionIV we present the proposed hybrid charging management framework. Followed by performance evaluation in V, we conclude our work in section VI.

2. Related Work

Previous literature on EV charging optimization focuses on single charging mode. With the maturity of V2V technology, research emerged in recent years takes the V2V charging as an alternative.

2.1. Plug-in Charging Mode

Charging EVs via statically deployed CSs is a dominant service mode [19]. However, as the number of EVs continues to grow, the promotion of plug-in charging mode is limited by land use and deployment location, charging power and operation cost [15]. It leads to charging service congestion when there are large number of concurrent charging requests, e.g., during charging peak hours.

Plenty of literature focus on how to maximize the utilization of CSs charging infrastructures. To stabilise the balance of charging services, the work in [20] allocates EV charging to CSs within a low demand period. To maximize the charging services rate within limited time constraints, the charging scheduling is formulated as a deadline (parking duration) constrained causal problem in the work [21]. Furthermore, the work in [22] proposes a preemptive charging strategy to improve the charging service provided for heterogeneous EVs.

However, above works are more concerned with perspective of service operators, which is against the EV driver's perspective (e.g., minimizing charging waiting time and price).

- Numerous literature works on minimizing charging waiting time. The work in [23] proves that, compared with selecting CS with the minimum distance, selecting CS with the minimum charging waiting time allows more EVs to receive charging service. Considering the mobility of EVs, the work in [24] proposes an optimization approach based on distributed decision. Here, the optimal CS-Selection is calculated by a heuristic algorithm, which effectively reduces charging waiting time.

- Influenced by price factors, the work in [25] considers EV charging priorities and charging price preferences of EV drivers, which results in a minimized total charging price. Meanwhile, the work in [26] minimizes charging price, by adjusting the price relating to charging service congestion level during different periods. Considering the continuous arrival of EVs, the work in [27] utilizes an online algorithm to recommend a CS-price pair for EV charging. Furthermore, the work in [28] optimizes charging management with a price flexibility strategy, by classifying EVs into charging categories via driving characteristics and charging requirements.

Nevertheless, above works lack consideration of unpredictable demand of charging services. A real-time charging scheme is proposed in [29], where EVs are coordinated through a demand response scheme. Unlike the work in [29], a charging intention detection is applied to detect charging demand in [30]. It is based on the historical CS preferences and real-time location of EVs. Considering the coincidence factor of charging demand for EVs, the influence of coincidence on EV charging is reduced based on model parameters in [31]. In [32], the reservation approach is introduced to reduce the impact of EV charging uncertainty under highway environments. The work in [33] further optimizes charging reservation in urban environments to minimize charging waiting time and maximizes charged EVs.

2.2. V2V Charging Mode

In recent years, the direct energy transfer among EVs has been proposed as an alternative to charging congestion [34]. The advantage of V2V charging mode is that it efficiently dispatches energy in the network using EVs as mobile charging resources [35]. However, the charging time under V2V mode is much longer due to slow charging power applied. This is mainly because that the battery lifetime is concerned given a peer-to-peer charging service, different from the business mode under plug-in charging [36].

Considering that EVs are on-the-move and that EV charging requests vary in the time domain, numerous literature mainly optimizes the dynamic matching of V2V-Pairs. The work in [37] models the V2V-Pair matching via a bipartite graph to maximize the number of EVs to be fully charged. Meanwhile, the work in [13] proposes a KM-based V2V-Pair matching method to reduce the travelling time and energy consumption. Nevertheless, above works do not guarantee V2V-Pair matching for EV-Cs. To solve this, the marriage algorithm is considered in [11], to maximize the EV charging utility (reduces distance and price cost). To maximize the number of V2V-Pairs matched and relieve pressure on the grid, the work in [38] encourages V2V with an incentive manner, based on a maximum weighted bipartite stable matching approach.

For EVs on-the-move, the selection of location for energy transfer (PL-Selection) is also crucial. Balanced charging services allocation at PLs would maximize charging infrastructures utilization and reduce charging waiting time. The work in [13] proposes a method that applies integrated mobile edge computing servers, to process the selection of movement path and PL.

Under the plug-in charging mode, charging price at CSs is influenced by the grid supply [39]. However, under the V2V charging mode, the price factor is complex as EV-Ps are also taken into account (EV-Ps' revenue in energy transfer). Here, price under V2V charging is volatile as location and residual energy of EV-Ps both influence EV-Ps willingness to provide energy. The work in [9] proposes a solution via an oligopolistic game. Here, it finds the equilibrium that maximizes the revenue of EV-Ps and minimizes the cost of EV-Cs. The work in [40] considers a buyer's market. Here, the revenue of EV-Ps is maximized by finding the extreme value point via a bidding model with Lagrange multipliers.

3. Preliminary

3.1. Assumption

In this paper, we consider a hybrid framework between the plug-in charging and V2V charging modes, aiming to take advantages of both modes under a holistic manner. In this framework, Global Controller (GC), CSs/PLs and

EVs are equipped with wireless communication modules so that they can communicate charging information over the cellular network. To protect the privacy of EVs, encrypted communication is applied between EVs and GC.

Table 1. List of Notations

ω_γ	Charging price coefficient
ω_ϵ	Charging waiting time coefficient
ω_λ	Charging energy coefficient
P^{cha}	CS charging power at slot / V2V charging power via converters
E_{ev}^{con}	Electric energy consumed per meter
E_{ev}^{max}	Full volume of EV battery
E_{ev}^{cur}	Current volume of EV battery
E_{ev}^{req}	Required charging volume of EV battery
E_{ev}^{cha}	Actual charging volume of EV battery
E_{ev}^{tra}	EV's energy consumption in travelling to CS/PL
T_{ϕ}^{arr}	EV's arrival time at CS / V2V-Pair's arrival time at PL
T_{cur}	Current time in the network
T_{ϕ}^{cha}	EV's charging time at CS / V2V-Pair's charging time at PL
T_{ϕ}^{wait}	EV/V2V-Pair's waiting time at CS/PL before it been charged
T_{ϕ}^{fin}	Charging finish time of EV / V2V-Pair
DIS_{ev}^{ev}	Distance between two EVs (an EV-C and another EV-P)
LIST	List includes available charging time for slots at CS / converters at PL
N_C	Queue of EVs under CS charging at CS / V2V charging at PL
N_W	Queue of EVs waiting for CS charging at CS / V2V charging at PL
N_R	Queue of EVs sending reservation to CS/PL
N_P^{ev}	Queue of EV-Ps
N_{PL}	Queue of PLs providing V2V charging
N_{CS}	Queue of CSs providing CS plug-in charging
N_{slot}	Number of charging slots at CS / Number of V2V converters at PL
D_{ev}	Parking duration of EV
S_{ev}	Speed of EV
$Cost_{ev}^{\Phi}$	Charging cost for EV / V2V-Pair to be charged at CS / PL
Note:	Φ and ϕ differs under plug-in/V2V charging modes, which is replaced by CS/PL or EV/V2V-Pair respectively.

3.2. Problem Formulation

Charging service quality is reflected into multiple dimensions. To propose a effective hybrid charging management, a comprehensive consideration of factors under different dimensions is required. Our proposed hybrid charging management aims to: 1) minimize the unit price of energy for charging services. 2) minimize the charging waiting time. 3) maximize charging energy per service. To formulate above objectives, we have follow sub-questions:

1. *Minimize Charging Price:* EV wants to be charged at providers with lower energy price, the total charging price for EVs is defined as R. The optimization objective is as follow:

$$\text{Minimize} \quad R = \sum_{l \in \mathbb{L}} \sum_{s_l \in S_l} P_{s_l} \times E_{s_l}^{cha} \tag{1}$$

   Here, $\mathbb{L}$ is the list of all EVs in the network. Considering that each EV may receive charging service for several times, each EV is with a charging service list S_l. The price of each charging service ($s_l \in S_l$) is calculated as the unit price of energy (P_{s_l}) multiplied by the amount of energy it charged ($E_{s_l}^{cha}$).
2. *Minimize Charging Waiting Time:* EV requires a reduced charging waiting time to shorten time spent at a CS/PL, the total charging waiting time for EVs is defined as W. The optimization objective is as follow:

$$\text{Minimize} \quad W = \sum_{l \in \mathbb{L}} \sum_{s_l \in S_l} T_{s_l}^{wait} \tag{2}$$

   Here, $T_{s_l}^{wait}$ represents the waiting time of an EV charging service.
3. *Maximize Charging Energy:* Considering the practical situation of limitations parking duration, EV aims to receive more charging energy, thus avoids frequent charging in the subsequent travelling. Here, the ratio of overall EVs' received charging energy is defined as Ω, the optimization objective is given as:

$$\text{Maximize} \quad \Omega = \sum_{l \in \mathbb{L}} \sum_{s_l \in S_l} \frac{E_{s_l}^{cha}}{E_{s_l}^{req}} \tag{3}$$

   EVs want to maximize the ratio of actual charging energy ($E_{s_l}^{cha}$) to the energy required ($E_{s_l}^{req}$).

Considering there exist repulsion, a charging cost ($Cost_{ev}^{\Phi}$) is proposed to balance each factor, which is given as follow:

$$Cost_{ev}^{\Phi} = \omega_\gamma * \frac{P_{local}}{P_{max}} + \omega_\epsilon * \frac{T_{\phi}^{wait}}{D_{ev}} - \omega_\lambda * \zeta * \frac{E_{ev}^{cha}}{E_{ev}^{req}} \tag{4}$$

Here, $Cost_{ev}^{\Phi}$ optimizes charging QoE in a joint consideration of three factors:

- **Charging Price Factor:** $(\omega_\gamma * \frac{P_{local}}{P_{max}})$ calculates the price factor. $\frac{P_{local}}{P_{max}}$ represents the ratio of the local energy price at a CS/PL (P_{local}) to the maximum energy price in the network (P_{max}). ω_γ represents the charging price coefficient. A lower charging price means that a CS/PL has a more significant advantage in terms of price.

- **Charging Waiting Time Factor:** $(\omega_\epsilon * \frac{T_\phi^{wait}}{D_{ev}})$ calculates the charging waiting time factor. ω_ϵ represents charging waiting time coefficient, $\frac{T_\phi^{wait}}{D_{ev}}$ calculates the ratio of charging waiting time (T_ϕ^{wait}) to the EV$_r$'s parking duration (D_{ev}). In case CS/PL is highly congested, this value may be greater than 1.

- **Charging Energy Factor:** $(\omega_\lambda * \zeta * \frac{E_{ev}^{cha}}{E_{ev}^{req}})$ calculates the charging energy factor. ω_λ represents charging energy coefficient. ζ indicates the rate of energy transfer through the converter (energy is lost during the transfer), which differs between V2V and plug-in charging modes. ζ is set as 86% under V2V charging mode [8] and 95% under plug-in charging mode. A higher charging energy factor means that EVs have a higher probability of receiving a fully charging service.

The calculation of $Cost_{ev}^{\Phi}$ is influenced by the predefined coefficients of ω_γ, ω_ϵ and ω_λ. The primary objective for EV charging is to replenish the driving range of EVs, therefore, ω_λ is weighted as the most important. The impact of energy price is weighted higher than the charging waiting time, provided that the charging service is guaranteed [41]. Based on the AHP [42], ω_γ, ω_ϵ and ω_λ are then defined as 0.2970, 0.1634 and 0.5396 respectively, thus $Cost_{ev}^{\Phi}$ is normalized as:

$$Cost_{ev}^{\Phi} = 0.2970 * \frac{P_{local}}{P_{max}} + 0.1634 * \frac{T_\phi^{wait}}{D_{ev}} - 0.5396 * \zeta * \frac{E_{ev}^{cha}}{E_{ev}^{req}} \tag{5}$$

4. Hybrid Charging Management Framework

Fig.1 demonstrates the framework of proposed hybrid charging management. Once the SOC of an EV-C falls below the preset threshold, it sends a charging request to the GC, the hybrid management is as follow:

- **V2V Charging Mode:** It contains V2V-Pair matching process and V2V charging process. The GC is responsible for V2V-Pair matching

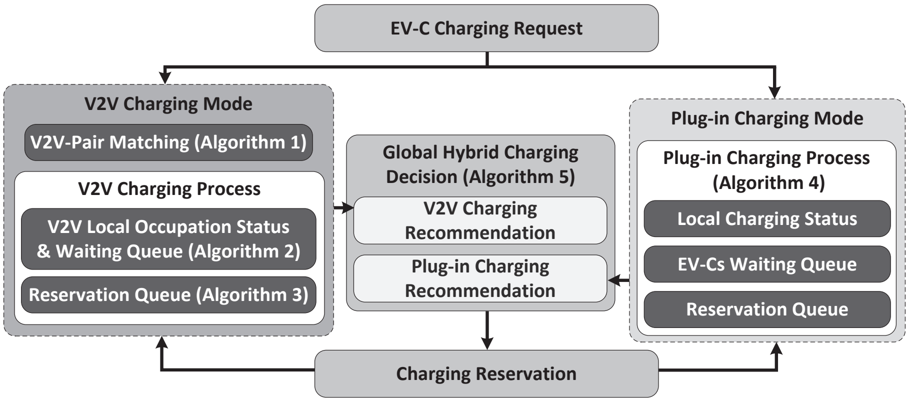


Fig. 1. Hybrid Charging Management Framework

by referring EVs' current location (Algorithm 1). In the V2V charging process, PL schedules its charging queue, including the current occupancy queue (V2V-Pairs under charging), the subsequent queue for V2V-Pairs waiting and reservation queue for V2V-Pairs that have sent charging reservations. The V2V charging cost at a PL is calculated at Algorithms 2 and 3.

- **Plug-in Charging Mode:** It contains a CS charging process. CS schedules the charging order of EV-Cs, which includes the current charging queue of EV-Cs, the waiting queue and the reservation queue of EV-Cs. Subsequently, the EV-C's charging cost at the CS can be calculated (Algorithm 4).

- **Global Hybrid Charging Decision:** The charging cost at overall CSs/PLs are aggregated to the GC for global decision making (Algorithm 5). This decision is then sent to the EV-C. Once the EV-C confirms the charging reservation, the information in hybrid charging management system is updated. It should be noted that charging reservation in this article is not a mandatory reservation, CSs/PLs do not reserve resources for subsequent EV-Cs. It is simply a resilient prediction mechanism, which allows the GC to be aware of the charging availability of different CS/PLs at a given point in time, e.g. the number of arrival EV-Cs, their estimated charging time. This helps the

GC avoid allocating charging services to CSs/PLs with high Charging Cost.

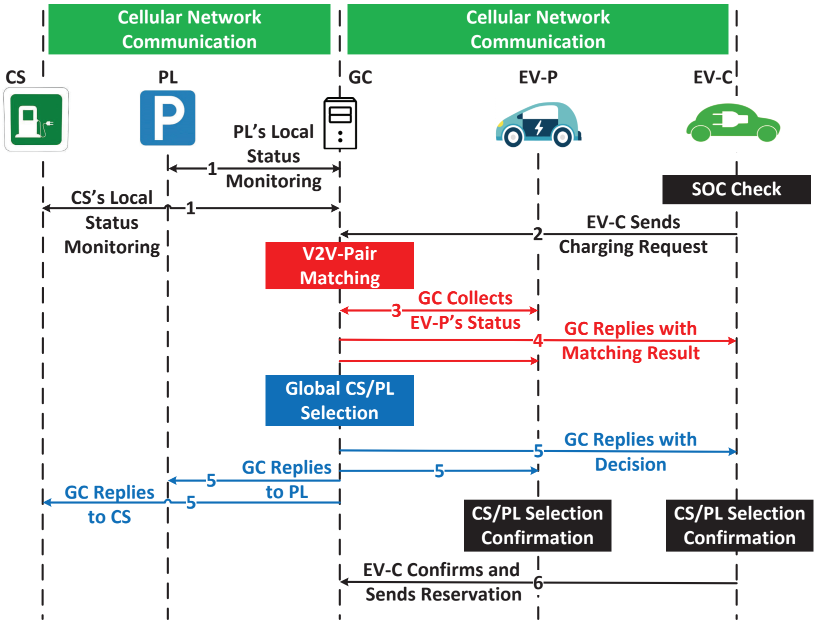


Fig. 2. Time Sequence for the Hybrid Charging Management

To provide a visual representation of the system procedures, the time sequence of hybrid charging system is illustrated in Fig.2:

Step 1: The GC monitors PLs and CSs to obtain their current status.

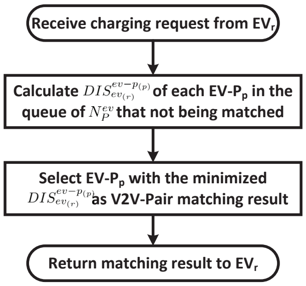
Step 2: Once the SOC of EV-C falls below the preset threshold, it sends a charging request to the GC.

Steps 3-4: The GC collects EV-Ps status and replies the V2V-Pair matching result to EVs.

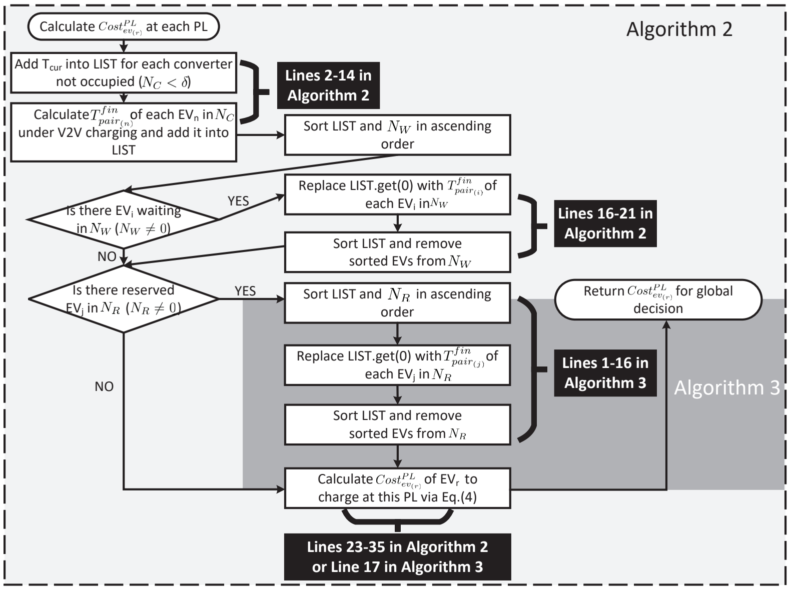
Step 5: The GC traverses all CSs/PLs to obtain the globally optimal decision (CS/PL with the lowest charging cost) between two charging modes and send the decision to the EV-C and CSs/PLs for confirmation.

Step 6: The EV-C confirms the charging decision (CS/PL-Selection) and replies charging reservation to the GC.

4.1. V2V Charging Mode



(a) Algorithm 1



(b) Algorithms 2 and 3

Fig. 3. Flowcharts of algorithms. (a) Algorithm 1. (b) Algorithms 2 and 3.

Algorithm 1 Pair Matching Algorithm

```
for $(p = 1; p \leq N_P^{ev}; p++)$ do
    if (EV-$P_p$ has not been matched) then
        calculate $DIS_{ev_{(r)}}^{ev-p_{(p)}}$
    end if
end for
EV-$P_p \leftarrow \arg\min(DIS_{ev_{(r)}}^{ev-p_{(p)}})$
return EV-$P_p$
```

Flowchart in Fig.3(a) demonstrates V2V-Pair matching process in Algorithm 1. When EV-C (EV$_r$) sends charging request to the GC, the GC matches the most suitable EV-P (with the minimized energy cost on-the-move) as the V2V-Pair of EV$_r$. Flowchart in Fig.3(b) demonstrates that all PLs are traversed in the charging network to obtain the V2V charging cost at each PL.

4.1.1. V2V-Pair Matching

In the Algorithm 1, the GC communicates with EV-Ps to aggregate their locations. The GC confirms whether an EV-P (EV-P$_p$) has been matched with other EV-C (line 2). If not, EV-P$_p$ is considered with service availability, then the distance between EV$_r$ and EV-P$_p$ is calculated at line 3. The EV-P$_p$ with the minimum distance is returned as the most suitable EV-P, thanks to the minimum energy consumed on-the-move (line 6). At line 7, the GC matches EV-P$_p$ as the result of V2V-Pair for EV$_r$. This pair matching result is replied to EV$_r$ and EV-Ps to ensure the stability of V2V-Pair matching.

4.1.2. V2V Charging Process

Lines from 2 to 13 in Algorithm 2 process PL local charging occupation status. If there is no converter at the PL currently occupied by V2V-Pairs, the current time in the network (T_{cur}) will be added to LIST with N_{slot} time at line 3. It indicates all converters (with number of N_{slot}) are available from T_{cur}. Here, LIST represents the available V2V charging time at each converter.

If there is EV (EV$_n$) in the queue of charging EVs at PL (N_C), the charging finish time of its V2V-Pair ($T^{fin}_{pair_{(n)}}$) will be added into LIST at line 6. This represents the converter is occupied by a V2V-Pair till $T^{fin}_{pair_{(n)}}$. It should be noted that the calculation of $T^{fin}_{pair_{(n)}}$ includes two cases:

- If the EV-C in a V2V-Pair can be fully charged, as the condition $((T_{cur}+T^{cha}_{pair_{(n)}}) \leq (T^{arr}_{pair_{(n)}} + D_{ev}))$, $T^{fin}_{pair_{(n)}}$ is given as the fully charging time of V2V-Pair ($T^{cha}_{pair_{(n)}} + T_{cur}$).
- If the EV-C in a V2V-Pair cannot be fully charged, $T^{fin}_{pair_{(n)}}$ is calculate as the V2V-Pair's departure deadline ($T^{arr}_{pair_{(n)}} + D_{ev}$). Then the V2V-Pair has to leave the PL at the upper limit of parking duration.

Algorithm 2 V2V Charging of Local V2V-Pairs

```
for each PL in $N_{PL}$ do
    if no EV is under charging then
        add $T_{cur}$ in LIST with $N_{slot}$ times
    end if
    for $(n = 1;\, n \leq N_C;\, n++)$ do
        LIST.ADD($T^{fin}_{pair_{(n)}}$)
    end for
    if $(N_C < N_{slot})$ then
        for $(m = 1; m \leq (N_{slot} - N_C); m++)$ do
            LIST.ADD($T_{cur}$)
        end for
    end if
    refine LIST with ascending order
    sort the queue of $N_W$
    if contains EVs waiting for charging then
        for $(i = 1; i \leq N_W; i++)$ do
            replace the LIST.GET(0) with $T^{fin}_{pair_{(i)}}$
            refine LIST with ascending order
            remove EV$_i$ from the queue of $N_W$
        end for
    end if
    if no EV's reservation for charging then
        $E^{req}_{ev_{(r)}} = E^{max}_{ev_{(r)}} - E^{cur}_{ev_{(r)}} - E^{tra}_{ev_{(r)}}$
        $T^{cha}_{pair_{(r)}} = \frac{E^{req}_{ev_{(r)}}}{P^{cha}}$
        if $((T^{cha}_{pair_{(r)}} +$ LIST.GET(0)$) < (D_{ev} + T^{arr}_{pair_{(r)}}))$ then
            $E^{cha}_{ev_{(r)}} = E^{req}_{ev_{(r)}}$
        else
            $E^{cha}_{ev_{(r)}} = (D_{ev} + T^{arr}_{pair_{(r)}} -$ LIST.GET(0)$) * P^{cha}$
        end if
        if $(T^{arr}_{pair_{(r)}} <$LIST.GET(0)$)$ then
            $T^{wait}_{pair_{(r)}} =$LIST.GET(0) $-T^{arr}_{pair_{(r)}}$
        else
            $T^{wait}_{pair_{(r)}} = 0$
        end if
        calculate $Cost^{PL}_{ev_{(r)}}$
        return $Cost^{PL}_{ev_{(r)}}$
    else
        return Algorithm 3 with input LIST
    end if
end for
```

$$T^{arr}_{pair_{(n)}} = \begin{cases} T^{arr}_{ev-p_{(n)}} & \text{if } (T^{arr}_{ev_{(n)}} \leq T^{arr}_{ev-p_{(n)}}) \\ T^{arr}_{ev_{(n)}} & \text{else} \end{cases} \tag{6}$$

Here, the arrival time of a V2V-Pair depends on the pair with later arrival time. Due to the difference in arrival times of EV-C and EV-P as V2V-Pair, EVs inevitably incur extra waiting time at PLs, and this would cause those EVs in the queue of N_W to wait.

To ensure LIST is with the earliest available charging time, it is sorted in ascending order at line 13. Lines from 14 to 21 process EV (EV$_i$) in the queue of N_W (EVs waiting to be charged). The for-loop from lines 16 to 20 updates the LIST by scheduling converters occupation of waiting V2V-Pair of EV$_i$. Line 17 replaces LIST.GET(0) with $T^{fin}_{pair_{(i)}}$ to indicate the first available converter would be occupied by EV$_i$ until $T^{fin}_{pair_{(i)}}$. Then LIST is sorted in ascending order at line 18 to make sure that LIST.GET(0) remains the first available charging time among converters. EV$_i$ that has been scheduled is removed from N_W at line 19. Subsequently, the remaining EVs in the queue of N_W, continue to be scheduled for V2V charging until all EVs in the queue of N_W have been ordered.

Based on whether the PL has V2V charging reservations, Algorithm 2 is divided into two cases:

- **Case 1 - No Reservation:** If the PL has not been reserved, LIST.GET(0) becomes the first available V2V charging time, after the scheduling of N_C and N_W queues. The charging cost for V2V charging through this PL can be calculated at line 35.
- **Case 2 - With Reservation:** If the PL has been reserved, then LIST is passed to Algorithm 3 for V2V charging scheduling with the reservation queue N_R at line 38.

4.1.3. Case 1 - No Reservation

At line 23 in Algorithm 2, the V2V charging energy requirement of EV$_r$ ($E^{req}_{ev_{(r)}}$) is calculated. Considering whether the EV$_r$ can be fully charged, the actual charging energy ($E^{cha}_{ev_{(r)}}$) is calculated between lines 24 and 28. If EV$_r$ can be fully charged, $E^{cha}_{ev_{(r)}}$ is equal to $E^{req}_{ev_{(r)}}$ at line 26. Conversely, at line 28, $E^{cha}_{ev_{(r)}}$ is calculated as the product of its actual charging time and charging power at the PL ($(D_{ev} + T^{arr}_{pair_{(r)}} -$LIST.GET(0)$) * P^{cha}$).

Lines from 30 to 34 calculate the charging waiting time ($T^{wait}_{pair_{(r)}}$). If the V2V-Pair of EV$_r$ arrives earlier than the earliest available charging converter ($T^{arr}_{pair_{(r)}}$ <LIST.GET(0)), $T^{wait}_{pair_{(r)}}$ is calculated as (LIST.GET(0) $-T^{arr}_{pair_{(r)}}$). Otherwise, $T^{wait}_{pair_{(r)}}$ equals 0, which means that EV$_r$ is able to directly receive V2V charging upon its arrival.

As core parameters ($E^{req}_{ev_{(r)}}$, $E^{cha}_{ev_{(r)}}$ and $T^{wait}_{pair_{(r)}}$) for calculating the charging cost have been obtained, Algorithm 2 calculates the charging cost at the PL at line 35. The charging cost calculation is detailed in section 3.2. Line 36 returns the charging cost for EV$_r$ to charge at the PL ($Cost^{PL}_{ev_{(r)}}$). This charging cost is then aggregated to further determine the optimal V2V charging PL.

Algorithm 3 V2V Charging of Reservation V2V-Pairs ⟨LIST⟩

```
 1: add EV$_r$ into the queue of $N_R$
 2: sort the queue of $N_R$
 3: for ($j = 1; j \leq N_R; j++$) do
 4:     if EV$_r$ equals to EV$_j$ then
 5:         break
 6:     else
 7:         if (($T^{cha}_{pair_{(j)}}$+ LIST.GET(0)) < ($D_{ev} + T^{arr}_{pair_{(j)}}$)) then
 8:             $T^{fin}_{pair_{(j)}} = T^{cha}_{pair_{(j)}}$+LIST.GET(0)
 9:         else
10:             $T^{fin}_{pair_{(j)}} = D_{ev} + T^{arr}_{pair_{(j)}}$
11:         end if
12:         replace the LIST.GET(0) with $T^{fin}_{pair_{(j)}}$
13:         sort LIST in ascending order
14:         remove EV$_j$ from the queue of $N_R$
15:     end if
16: end for
17: calculate $Cost^{PL}_{ev_{(r)}}$
18: return $Cost^{PL}_{ev_{(r)}}$
```

4.1.4. Case 2 - With Reservation

If a PL receives V2V charging reservations (at line 37 in Algorithm 2), it is necessary to sort the charging scheduling of other EVs (and their corresponding V2V-Pairs) in the queue of N_R with EV$_r$. Thus, at line 38, LIST is passed to Algorithm 3 for further V2V charging scheduling and charging cost calculation.

In Algorithm 3, EV_r is added into the queue of N_R at line 1. EV (EV_j) in the queue of N_R is sorted in ascending order. This is to ensure EV_j can receive V2V charging in the order of their arrival time. The for-loop operation from lines 3 to 16 schedules the V2V charging of EV_j in N_R. At line 5, the for-loop would break if EV_j in that loop is equal to EV_r. Otherwise, EV_j would charge prior to EV_r. $T^{fin}_{pair_{(j)}}$ is calculated separately at lines 8 and 10, corresponding to the fully charged and not fully charged cases. Then LIST.GET(0) is replaced by $T^{fin}_{pair_{(j)}}$, meaning that the earliest available converter is occupied by the V2V-Pair of EV_j till its charging finished. EV_j been scheduled is removed from N_R at line 14.

When the for-loop is finished, parameters for EV_r to charge at that PL ($E^{req}_{ev_{(r)}}$, $E^{cha}_{ev_{(r)}}$ and $T^{wait}_{pair_{(r)}}$) can be calculated. With above parameters, Algorithm 3 calculates $Cost^{PL}_{ev_{(r)}}$ at line 17 and outputs this value as the charging cost of EV_r to have V2V charging at this PL.

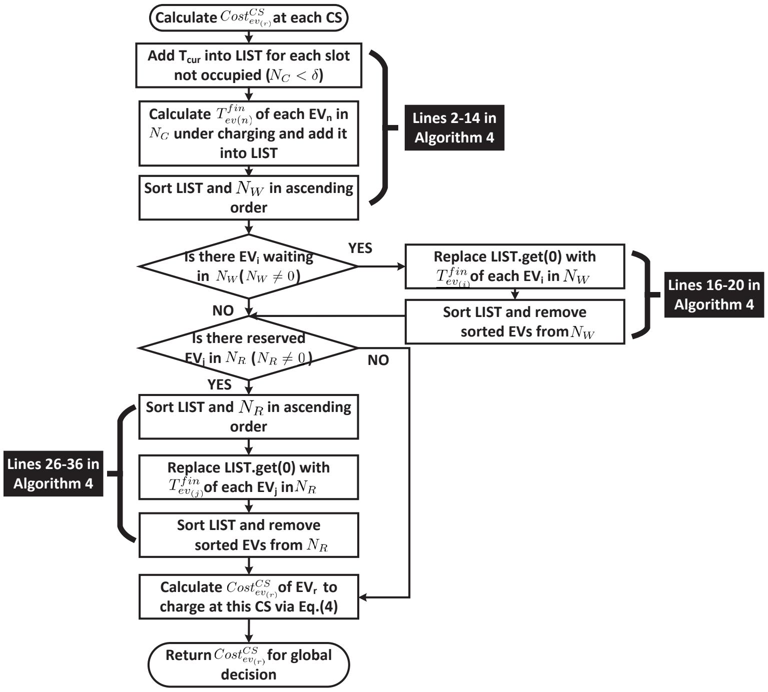
4.2. CS Charging Mode

In Algorithm 4, a global for-loop traverses all CSs in the charging network, to obtain the charging cost at each CS under the CS charging mode. Such process is demonstrated in Fig.4(a).

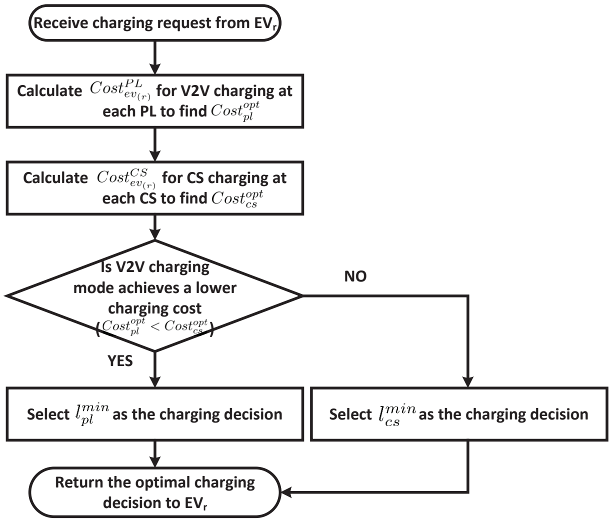
The EVs under charging is characterized in the queue of N_C. Here, T_{cur} will be added into the LIST with N_{slot} times to indicate that all slots are available from T_{cur}. Lines from 5 to 7 update the LIST by traversing charging service of EV_n (EV in the queue of N_C). $T^{fin}_{ev(n)}$ is added into LIST at line 6 to indicate that a charging slot is providing service to EV_n until $T^{fin}_{ev(n)}$. Lines between 8 and 12 consider the situation that not all charging slots are occupied, T_{cur} will be added to the LIST with $(N_{slot} - N_C)$ times. Followed by lines 13 and 14, Algorithm 4 schedules the LIST in ascending order.

Lines from 14 to 21 process EVs parked at the CS waiting for charging. To obtain the occupation status of converters, EV_i in the queue of N_W is calculated. For each EV_i, its $T^{fin}_{ev_{(i)}}$ would replace LIST.GET(0) to indicate its occupancy status for the charging slot. Then LIST is sorted in ascending order at line 18, to make sure that LIST.GET(0) remains the first available charging time among converters. EV_i that has been scheduled is removed from N_W at line 19. Those EVs not been removed, continue to be scheduled until they have been ordered.

If the CS has no charging reservation received, EV_r is scheduled with the top charging order after EV_i been charged. The charging cost ($Cost^{CS}_{ev_{(r)}}$)



(a) Algorithm 4



(b) Algorithm 5

Fig. 4. Flowcharts of algorithms. (a) Algorithm 4. (b) Algorithm 5.

Algorithm 4 CS Charging of Local EV-Cs

```
for each CS in $N_{CS}$ do
    if no EV is under charging then
        add $T_{cur}$ in LIST with $N_{slot}$ times
    end if
    for $(n = 1; n \leq N_C; n++)$ do
        LIST.ADD($T^{fin}_{ev(n)}$)
    end for
    if $(N_C < N_{slot})$ then
        for $(m = 1; m \leq (N_{slot} - N_C); m++)$ do
            LIST.ADD($T_{cur}$)
        end for
    end if
    refine LIST with ascending order
    sort the queue of $N_W$
    if contains EVs waiting for charging then
        for $(i = 1; i \leq N_W; i++)$ do
            replace the LIST.GET(0) with $T^{fin}_{ev_{(i)}}$
            refine LIST with ascending order
            remove EV$_i$ from the queue of $N_W$
        end for
    end if
    if no EV's reservation for charging then
        calculate $Cost^{CS}_{ev_{(r)}}$
        return $Cost^{CS}_{ev_{(r)}}$
    else
        add EV$_r$ into the queue of $N_R$
        sort the queue of $N_R$
        for $(j = 1; j \leq N_R; j++)$ do
            if EV$_r$ equals to EV$_j$ then
                break
            else
                replace the LIST.GET(0) with $T^{fin}_{ev_{(j)}}$
                sort LIST in ascending order
                remove EV$_j$ from the queue of $N_R$
            end if
        end for
        calculate $Cost^{CS}_{ev_{(r)}}$
        return $Cost^{CS}_{ev_{(r)}}$
    end if
end for
```

of EV$_r$ at this CS can be calculated at line 23. This $Cost^{CS}_{ev_{(r)}}$ is return for the global hybrid charging decision making. Lines from 25 to 38 consider the condition that this CS has charging reservation received. If EV$_j$ (the EV in the queue of N_R being processed in current loop operation) is the EV$_r$. This implies that EV$_r$ is able to be charged upon its arrival. If not, EV$_j$'s charging finish time $T^{fin}_{ev_{(j)}}$ will take place LIST.GET(0). Then LIST is sorted in ascending order and EV$_j$ that has been scheduled is removed from N_R. Once EV$_r$ has been determined its charging order, $Cost^{CS}_{ev_{(r)}}$ can be calculated. Such $Cost^{CS}_{ev_{(r)}}$ is returned to Algorithm 5 at line 38 for final charging decision making.

Algorithm 5 Global Hybrid Charging Decision Making

```
1: for $\forall l_{pl} \in N_{PL}$ do
2:     calculate $Cost^{PL}_{ev_{(r)}}$ via Algorithm 2 and 3
3: end for
4: $Cost^{opt}_{pl} \leftarrow \arg\min(Cost^{PL}_{ev_{(r)}})$
5: for $\forall l_{cs} \in N_{CS}$ do
6:     calculate $Cost^{CS}_{ev_{(r)}}$ via Algorithm 4
7: end for
8: $Cost^{opt}_{cs} \leftarrow \arg\min(Cost^{CS}_{ev_{(r)}})$
9: if $Cost^{opt}_{pl} < Cost^{opt}_{cs}$ then
10:     return $l^{min}_{pl}$
11: else
12:     return $l^{min}_{cs}$
13: end if
```

4.3. Global Hybrid Charging Decision

In order to serve EVs with desire QoE, in Algorithm 5, the GC aggregates $Cost^{\Phi}_{ev}$ via Algorithm 2, 3 and 4, and determines the global hybrid charging decision selection. Here, the process of Algorithm 5 is demonstrated in Fig.4(b).

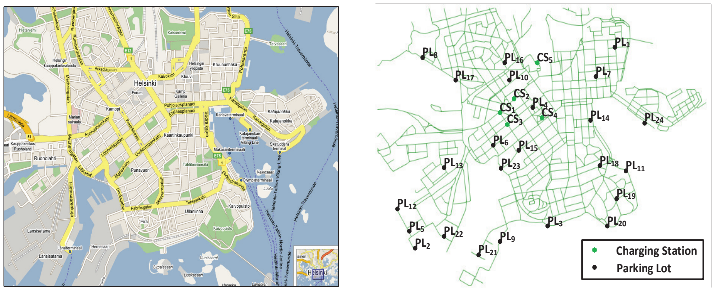
The for-loop from lines 1 to 3 traverses all PLs in the charging network to calculates their $Cost^{PL}_{ev_{(r)}}$. Then the PL with the lowest $Cost^{PL}_{ev_{(r)}}$ would be selected as optimal V2V charging selection. This PL-Selection determines the minimum charging cost ($Cost^{opt}_{pl}$) under V2V charging mode.

All CSs in the charging network are traversed between lines 5 and 8. Their charging cost ($Cost^{CS}_{ev_{(r)}}$) are calculated. The CS with the lowest $Cost^{opt}_{cs}$ will be determined as CS-Selection for global hybrid selection at line 8.

Based on the minimized charging cost, the optimal PL-Selection and CS-Selection are identified at line 5 and line 8 respectively, which takes into account the charging price, the charging waiting time and the actual charged energy. Therefore, if the condition ($Cost_{pl}^{opt} < Cost_{cs}^{opt}$) holds, the optimal PL (l_{pl}^{min}) will be recommended for EV_r as its allocated charging decision; Otherwise, the optimal CS (l_{cs}^{min}) will be recommended for EV_r.

5. Performance Evaluation

5.1. Simulation Configuration



(a) Google Map of Helsinki City (b) Deployment of CSs/PLs

Fig. 5. Simulation Scenario

The Opportunistic Network Environment (ONE) [43] is applied to simulate EV charging network scenario. In Fig.5(b), the simulation demonstrates the urban area of Helsinki city (Fig.5(a)) with a $4500 \times 3400\ m^2$ scenario. 24 PLs are geographically deployed in the urban area and each PL is equipped with 4 DC-DC converters. The DC-DC converter allows charging for a V2V-Pair with an energy transfer power of 15 kW. Meanwhile, 5 CSs are deployed in this urban scenario, and each is provided with 4 charging slots using the fast charging power of 52 kW. The benchmark price in the network is set as plug-in charging price with €0.25 /kWh [44]. To represent the price variation of V2V charging and the impact of PL availability on the price, we introduce a grading price in simulation as listed in Table 2.

Table 2. V2V Charging price at PL (€/kWh)

	Urban Areas	Suburban Areas
All Converters Available	0.10	0.12
Half Converters Available	0.15	0.16
All Converters Occupied	0.20	0.20

EVs in the scenario are divided into three types, with the following configuration: Maximum Electricity Capacity (MEC), Max Travelling Distance (MTD), Average Energy Consumption (AEC) and SOC threshold. Table 3 lists configuration of EVs.

Table 3. EV configuration

	Coda [45]	Wheego whip [46]	BlueOn[47]
MEC (kWh)	33.8	30.0	16.4
MTD (km)	193	161	140
AEC (kWh/km)	0.1751	0.1863	0.1171
SOC threshold	30%	40%	50%

EV-C battery is with full volume at the beginning. Meanwhile, the number of EV-Ps is set as the same number of EV-Cs (to ensure stable V2V-Pair matching). EV-Ps are set to have enough energy to provide multiple V2V charging service, thus they don't require intermediate charging.

EVs are with moving speed from 30 to 50 km/h, to reflect situation of roads and traffic. Here, destinations of EVs are set randomly. If the SOC of an EV-C is below the threshold, it sends charging request to the GC for charging decision. When the EV receives CS/PL-Selection and confirms the charging reservation, it travels to the selected CS/PL along the Helsinki city road topology. The real-time location and energy information of EVs are updated at a frequency of 0.1s. The simulation lasts for a duration of 12 hours.

5.2. Comparison Configuration

A hybrid charging management scheme is proposed in this paper. The following charging schemes are evaluated for comparison:

- **Reservation-based Hybrid Charging Management (R-Hyb)**: The proposed scheme with hybrid charging management that selects the CS/PL with the minimized charging cost, with reservation.
- **Hybrid Charging Management without Reservation (Hyb)**: The benchmark scheme with hybrid charging management that selects the CS/PL with the minimized charging cost, without reservation.

We evaluate two other schemes under single plug-in or V2V mode.

- **Reservation-based V2V Charging (R-V2V) [14]**: Literature work applies the V2V charging mode with reservation. The GC allocates V2V-Pairs to the PL with the earliest available charging time.
- **Reservation-based plug-in Charging (R-CS) [33]**: Literature work applies the plug-in charging mode with reservation. The GC allocates EVs to the CS with the earliest available charging time.

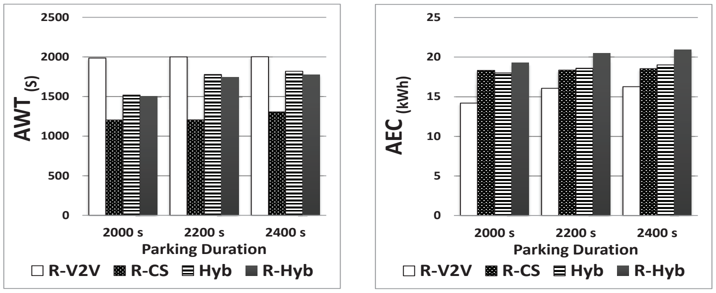
The following performance metrics are evaluated:

- **Average Charging Price per unit (ACP)**: It indicates the average charging price of EV-Cs charged at CS/PL.
- **Average Waiting Time (AWT)**: It indicates the average waiting time for EV-Cs between they arrive at CS/PL and receive charging service.
- **Average Energy Charging (AEC)**: It indicates the average energy of EV-Cs charged per charging service.
- **Charging Cost**: It indicates the average charging cost of each EV during the entire duration of simulation. Here, lower charging cost refers better QoE.

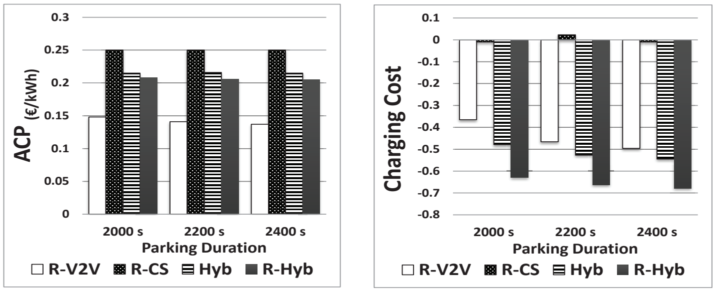
5.3. Influence of Parking Duration

In the first group of simulations, we set the EV density to 150 (including 150 EV-Cs and 150 EV-Ps) and observe the influence of parking duration.

R-Hyb scheme achieves a shorter AWT comparing with Hyb scheme in Fig.6(a). As the parking duration increases, there is a significant increase of AWT under both hybrid modes. Since charging cost is considered, the



(a) AWT (b) AEC



(c) ACP (d) Charging Cost

Fig. 6. Influence of Parking Duration

increase of parking duration means that hybrid modes accept a longer waiting time in exchange for sufficient charging energy ($\omega_\lambda = 0.5396$).

Due to the high coefficients of charging energy, R-Hyb scheme achieves the highest AEC. Meanwhile, when the parking duration increases in Fig.6(b), AEC under R-Hyb scheme has the most significant increment. Hyb scheme suffers with a lower AEC than that of R-Hyb scheme by 14%, due to the lack of a priori information. In Fig.6(c), R-V2V scheme achieves the lowest ACP as it only allows V2V charging (with a lower charging price). The ACP under R-CS scheme, on the other hand, is fixed at €0.25 /kWh. The ACP of R-Hyb and Hyb schemes are concentrated around €0.2 /kWh. This is because their optimization jointly consider both charging modes. In addition, parking duration have low influence on the ACP, as the coefficients of charging price is low ($\omega_\epsilon = 0.1634$).

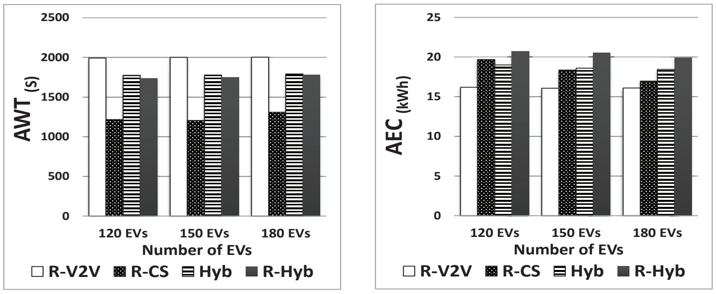
The charging cost of EVs is illustrated in Fig.6(d). Here, the charging cost of R-Hyb scheme decreases when the parking duration increases. Meanwhile, R-Hyb scheme achieves the lowest charging cost. The improvement in charging cost for R-Hyb compared to Hyb is about 33%. The improvement in charging cost for R-Hyb compared to R-V2V is about 65%, which is most significant when the parking duration is short (meaning higher charging congestion). This indicates that R-Hyb scheme ensures EV-Cs receiving services with high QoE, thanks to the consideration of hybrid charging mode, as well as charging reservation.

5.4. Influence of EV Density

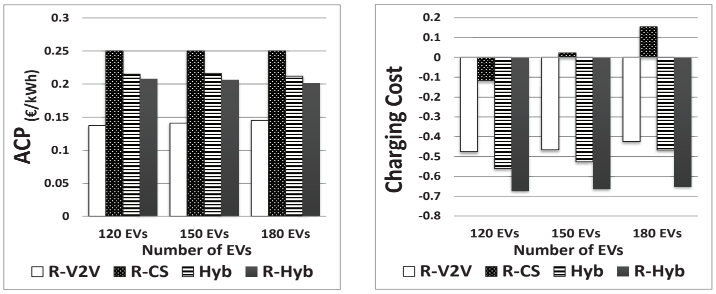
In the second group of simulations, we set the parking duration to 2200s and observe the influence of EV density.

In Fig.7(a), R-CS scheme achieves the shortest AWT above all schemes. However, it is worth noting that there is a significant increase in AWT of R-CS scheme when the number of EVs increases. This reflects that, limited by the rigid deployment of CSs, R-CS scheme can not avoid charging congestion when it faces with large concurrent charging requests. In comparison, R-Hyb scheme maintains a lower level of AWT when the number of EVs increases.

As the number of EVs increases, AEC under each of the schemes decreases (Fig.7(b)). Here, R-Hyb achieves the highest AEC due to the introduction of charging cost as an optimization objective. Meanwhile, R-Hyb scheme considers hybrid charging, thus allowing for a maximized utilization of charging resources. As R-Hyb avoids allocating EVs to CSs/PLs with high charging



(a) AWT (b) AEC



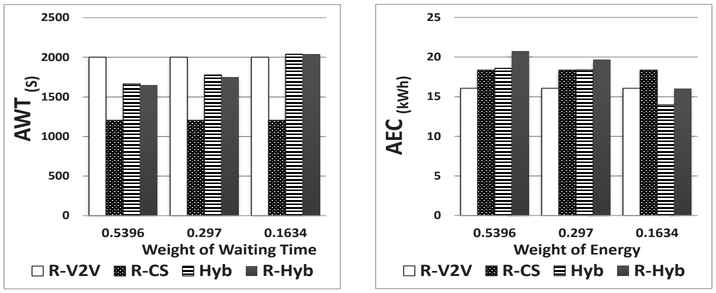
(c) ACP (d) Charging Cost

Fig. 7. Influence of EV Density

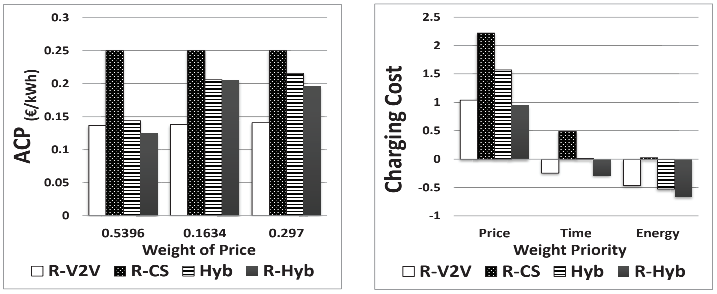
congestion and considers hybrid charging, it helps R-Hyb scheme to maximized utilize charging resources. This results in that the ACP under R-Hyb scheme decreases even when the number of EVs increases (Fig.7(c)).

In Fig.7(d), both R-CS and R-V2V schemes have significant increase in charging cost when the number of EVs increases, which means that the QoE of EV charging can not be guaranteed. This is due to a longer charging waiting time caused by charging congestion. However, R-Hyb scheme still achieves the lowest charging cost, due to the consideration of hybrid charging and charging reservation. Even if the number of EVs increases significantly, the increase in charging cost under R-Hyb is about only 3%. This refers that R-Hyb can guarantee QoE by flexibly utilizing charging resources in the network.

5.5. Influence of AHP Coefficients Weight



(a) AWT (b) AEC



(c) ACP (d) Charging Cost

Fig. 8. Influence of AHP Coefficients Weighting

In Eq.(5), the coefficient weight in the judgement matrix is assigned according to AHP. Due to that the coefficient of charging energy ($\omega_\lambda = 0.5396$)

is the highest, AEC among all metrics varies the most significant. Therefore, in this group of simulation, we adjust the weight of each coefficient. Here, the parking duration is set to 2200s and the number of EVs is set to 150. The results of changing weight for ω_γ, ω_ϵ and ω_λ respectively are shown in Fig.7(a-c). This is to see how each coefficient has an effect on performance metrics under different levels of weight.

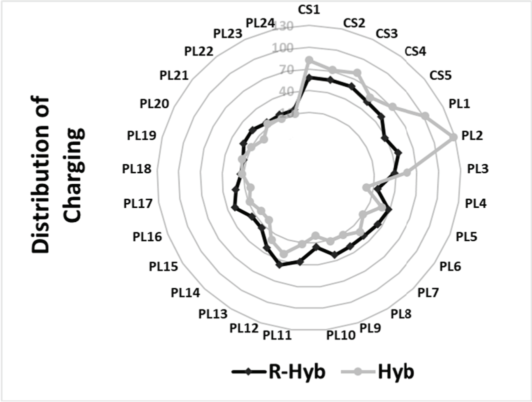
In Fig.8(a), ω_ϵ is set to 0.5396, 0.2970 and 0.1634 respectively. The results reflect that AWT of R-Hyb increases as ω_ϵ decreases. When ω_ϵ is 0.5396, both hybrid schemes achieve lower AWT than R-V2V scheme, while still higher than R-CS scheme. However, Hyb scheme suffers a higher AWT comparing with R-Hyb scheme, which reflects the importance of reservation. In Fig.8(b), ω_λ is changed. It should be noted that AEC under R-Hyb is even lower than that under R-V2V scheme, when ω_λ is set to 0.1634. This reflects the importance of individual coefficient weight settings. Meanwhile, in Fig.8(c), ACP under R-Hyb is the lowest when the weight of ω_γ is the highest.

In Fig.8(d), results show charging cost when each coefficient is set with the highest weight priority. Here, the density of EVs and the parking duration are set same. When ω_λ's weight is set as the highest ($\omega_\lambda = 0.5396$), the charging cost of all schemes are at the lowest level. This illustrates the improvement of overall EV charging QoE when charging energy is given priority. Nevertheless, for the purpose of optimizing EV charging, coefficient weights could be adjusted by EV charging network operators to suit different charging scenarios.

5.6. Distribution of Charging at CSs/PLs

Fig.9(a) illustrates the charging distribution at different CSs/PLs under R-Hyb and Hyb schemes. Here, the simulation is set with 150 EVs and 2200s parking duration.

An even distribution among CSs/PLs could maximize the utilization of charging resources. As Hyb scheme makes charging decision without reservation, CSs/PLs in urban centre would be selected frequently. This inevitably causes charging congestion and reduces the QoE of EV drivers. However, R-Hyb scheme ensures a relatively even distribution of charging among all CSs/PLs. This reflects that R-Hyb makes better utilization of charging resources in the network. When the charging network is faced with a large number of concurrent EV charging requests, R-Hyb can still guarantee a high QoE.



(a) Distribution

Fig. 9. Distribution of Charging at CSs/PLs

6. Conclusion

Currently, a single charging mode cannot handle a large number of concurrent EVs charging requests. Therefore, we propose a hybrid charging management scheme to flexibly utilise both plug-in charging and V2V charging modes. To improve the QoE of EV charging, the proposed hybrid management introduces a charging cost based on a collaborative optimization of price-time-energy dimensions. When determining the charging allocation for EVs, the proposed hybrid management selects the CS/PL with the lowest charging cost. Considering the high mobility of EVs, the hybrid charging management further introduces charging reservation. This allows a more accurate assessment of charging availability of each CS/PL, to make optimal utilization of charging resources in the network. In this paper, a EV charging network is simulated under Helsinki urban scenario. The results show that the proposed reservation-based hybrid scheme can effectively improve the EV charging QoE, with higher charging energy, lower charging waiting times and charging price.

7. Acknowledgements

This work is supported in part by the Hubei Province International Science and Technology Collaboration Program (2022EHB002) and Wuhan Key Research and Development Program (2022012202015016).

References

[1] A. S. Al-Ogaili, T. J. Tengku Hashim, N. A. Rahmat, A. K. Ramasamy, M. B. Marsadek, M. Faisal, M. A. Hannan, Review on scheduling, clustering, and forecasting strategies for controlling electric vehicle charging: Challenges and recommendations, IEEE Access 7 (2019) 128353–128371. doi:10.1109/ACCESS.2019.2939595.

[2] Y. Cao, H. Song, O. Kaiwartya, A. Lei, Y. Wang, G. Putrus, Electric vehicle charging recommendation and enabling ict technologies: recent advances and future directions, IEEE COMSOC MMTC Communications-Frontiers 12 (6) (2017) 23–32.

[3] J. Kim, S. Bae, Optimal installation of electric vehicle charging stations using fleet-vehicles data, in: 2020 IEEE Power & Energy Society General Meeting (PESGM), 2020, pp. 1–5. doi:10.1109/PESGM41954.2020.9281788.

[4] X. Mou, R. Zhao, D. T. Gladwin, Vehicle-to-vehicle charging system fundamental and design comparison, in: 2019 IEEE International Conference on Industrial Technology (ICIT), IEEE, 2019, pp. 1628–1633.

[5] G. G. Kumar, K. Sundaramoorthy, Dual-input nonisolated dc-dc converter with vehicle-to-grid feature, IEEE Journal of Emerging and Selected Topics in Power Electronics 10 (3) (2022) 3324–3336. doi:10.1109/JESTPE.2020.3042967.

[6] R. Alvaro-Hermana, J. Fraile-Ardanuy, P. J. Zufiria, L. Knapen, D. Janssens, Peer to peer energy trading with electric vehicles, IEEE Intelligent Transportation Systems Magazine 8 (3) (2016) 33–44. doi:10.1109/MITS.2016.2573178.

[7] T. J. C. Sousa, L. Machado, D. Pedrosa, C. Martins, V. Monteiro, J. L. Afonso, Comparative analysis of vehicle-to-vehicle (v2v) power transfer configurations without additional power converters, in: 2020 IEEE 14th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), Vol. 1, 2020, pp. 88–93. doi:10.1109/CPE-POWERENG48600.2020.9161697.

[8] A. Koufakis, E. S. Rigas, N. Bassiliades, S. D. Ramchurn, Offline and online electric vehicle charging scheduling with v2v energy transfer, IEEE

Transactions on Intelligent Transportation Systems 21 (5) (2020) 2128–2138. doi:10.1109/TITS.2019.2914087.

[9] P. You, Z. Yang, M.-Y. Chow, Y. Sun, Optimal cooperative charging strategy for a smart charging station of electric vehicles, in: 2017 IEEE Power Energy Society General Meeting, 2017, pp. 1–1. doi:10.1109/PESGM.2017.8274008.

[10] N. K. Meena, J. Yang, Optimization framework for peer-to-peer charging of electric vehicles in multi-area distribution networks, in: 2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), 2019, pp. 1–5. doi:10.1109/ISGTEurope.2019.8905531.

[11] R. Zhang, X. Cheng, L. Yang, Flexible energy management protocol for cooperative ev-to-ev charging, IEEE Transactions on Intelligent Transportation Systems 20 (1) (2019) 172–184. doi:10.1109/TITS.2018.2807184.

[12] H. Tu, H. Feng, S. Srdic, S. Lukic, Extreme fast charging of electric vehicles: A technology overview, IEEE Transactions on Transportation Electrification 5 (4) (2019) 861–878. doi:10.1109/TTE.2019.2958709.

[13] G. Li, Q. Sun, L. Boukhatem, J. Wu, J. Yang, Intelligent vehicle-to-vehicle charging navigation for mobile electric vehicles via vanet-based communication, IEEE Access 7 (2019) 170888–170906. doi:10.1109/ACCESS.2019.2955927.

[14] S. Liu, Q. Ni, Y. Cao, J. Cui, D. Tian, Y. Zhuang, A reservation-based vehicle-to-vehicle charging service under constraint of parking duration, IEEE Systems Journal (2022) 1–10doi:10.1109/JSYST.2022.3145155.

[15] T. Chen, X.-P. Zhang, J. Wang, J. Li, C. Wu, M. Hu, H. Bian, A review on electric vehicle charging infrastructure development in the uk, Journal of Modern Power Systems and Clean Energy 8 (2) (2020) 193–205. doi:10.35833/MPCE.2018.000374.

[16] S. Aznavi, P. Fajri, M. B. Shadmand, A. Khoshkbar-Sadigh, Peer-to-peer operation strategy of pv equipped office buildings and charging stations considering electric vehicle energy pricing, IEEE Transactions on Industry Applications 56 (5) (2020) 5848–5857. doi:10.1109/TIA.2020.2990585.

[17] S. Haider, R. e Zahra Rizvi, J. Walewski, P. Schegner, Investigating peer-to-peer power transactions for reducing ev induced network congestion, Energy 254 (2022) 124317. doi:https://doi.org/10.1016/j.energy.2022.124317.
URL `https://www.sciencedirect.com/science/article/pii/S0360544222012208`

[18] L. Zeng, C. Li, Z. Li, M. Shahidehpour, B. Zhou, Q. Zhou, Hierarchical bipartite graph matching method for transactive v2v power exchange in distribution power system, IEEE Transactions on Smart Grid 12 (1) (2021) 301–311. doi:10.1109/TSG.2020.3016597.

[19] P. Jog, S. Shete, R. K. Kumawat, D. Palwalia, Electric vehicle charging station infrastructure: A review, in: 2021 6th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE), Vol. 6, 2021, pp. 1–7. doi:10.1109/ICRAIE52900.2021.9703969.

[20] J. Timpner, L. Wolf, Design and evaluation of charging station scheduling strategies for electric vehicles, IEEE Transactions on Intelligent Transportation Systems 15 (2) (2014) 579–588.

[21] Z. Wei, Y. Li, Y. Zhang, L. Cai, Intelligent parking garage ev charging scheduling considering battery charging characteristic, IEEE Transactions on Industrial Electronics 65 (3) (2018) 2806–2816. doi:10.1109/TIE.2017.2740834.

[22] Y. Cao, S. Liu, Z. He, X. Dai, X. Xie, R. Wang, S. Yu, Electric vehicle charging reservation under preemptive service, in: 2019 1st International Conference on Industrial Artificial Intelligence (IAI), 2019, pp. 1–6. doi:10.1109/ICIAI.2019.8850812.

[23] M. Gharbaoui, L. Valcarenghi, R. Bruno, B. Martini, M. Conti, P. Castoldi, An Advanced Smart Management System for Electric Vehicle Recharge, in: IEEE IEVC' 12, Greenville, SC, USA, 2012.

[24] Q. Tang, K. Wang, Y. Song, F. Li, J. H. Park, Waiting time minimized charging and discharging strategy based on mobile edge computing supported by software-defined network, IEEE Internet of Things Journal 7 (7) (2020) 6088–6101. doi:10.1109/JIOT.2019.2957124.

[25] L. Yao, W. H. Lim, T. S. Tsai, A real-time charging scheme for demand response in electric vehicle parking station, IEEE Transactions on Smart Grid 8 (1) (2017) 52–62. doi:10.1109/TSG.2016.2582749.

[26] E. Rigas, S. Ramchurn, N. Bassiliades, G. Koutitas, Congestion Management for Urban EV Charging Systems, in: IEEE SmartGridComm '13, Vancouver, Canada, 2013.

[27] B. Sun, T. Li, S. H. Low, D. H. K. Tsang, Orc: An online competitive algorithm for recommendation and charging schedule in electric vehicle charging network, in: Proceedings of the Eleventh ACM International Conference on Future Energy Systems, e-Energy '20, Association for Computing Machinery, New York, NY, USA, 2020, p. 144–155. doi:10.1145/3396851.3397727.
URL `https://doi.org/10.1145/3396851.3397727`

[28] L. Liu, K. Zhou, Electric vehicle charging scheduling considering urgent demand under different charging modes, Energy 249 (2022) 123714. doi:https://doi.org/10.1016/j.energy.2022.123714.
URL `https://www.sciencedirect.com/science/article/pii/S036054422200617X`

[29] L. Yao, W. H. Lim, T. Tsai, A real-time charging scheme for demand response in electric vehicle parking station, IEEE Transactions on Smart Grid 8 (2017) 52–62. doi:10.1109/TSG.2016.2582749.

[30] Z. Tian, T. Jung, Y. Wang, F. Zhang, L. Tu, C. Xu, C. Tian, X. Li, Real-time charging station recommendation system for electric-vehicle taxis, IEEE Transactions on Intelligent Transportation Systems 17 (11) (2016) 3098–3109.

[31] J. Bollerslev, P. B. Andersen, T. V. Jensen, M. Marinelli, A. Thingvad, L. Calearo, T. Weckesser, Coincidence factors for domestic ev charging from driving and plug-in behavior, IEEE Transactions on Transportation Electrification 8 (1) (2022) 808–819. doi:10.1109/TTE.2021.3088275.

[32] H. Qin, W. Zhang, Charging Scheduling With Minimal Waiting in a Network of Electric Vehicles and Charging Stations, in: ACM VANET ' 11, Las Vegas, Nevada, USA, 2011.

[33] Y. Cao, N. Wang, G. Kamel, Y.-J. Kim, An Electric Vehicle Charging Management Scheme Based on Publish/Subscribe Communication Framework, IEEE Systems Journal PP (99) (2015) 1–14.

[34] A. Koufakis, E. S. Rigas, N. Bassiliades, S. D. Ramchurn, Towards an optimal ev charging scheduling scheme with v2g and v2v energy transfer, in: 2016 IEEE International Conference on Smart Grid Communications (SmartGridComm), 2016, pp. 302–307. doi:10.1109/SmartGridComm.2016.7778778.

[35] C. Liu, K. T. Chau, D. Wu, S. Gao, Opportunities and challenges of vehicle-to-home, vehicle-to-vehicle, and vehicle-to-grid technologies, Proceedings of the IEEE 101 (11) (2013) 2409–2427. doi:10.1109/JPROC.2013.2271951.

[36] E. Ucer, R. Buckreus, M. C. Kisacikoglu, E. Bulut, M. Guven, Y. Sozer, L. Giubbolini, A flexible v2v charger as a new layer of vehicle-grid integration framework, in: 2019 IEEE Transportation Electrification Conference and Expo (ITEC), 2019, pp. 1–7. doi:10.1109/ITEC.2019.8790483.

[37] E. Bulut, M. C. Kisacikoglu, Mitigating range anxiety via vehicle-to-vehicle social charging system, in: 2017 IEEE 85th Vehicular Technology Conference (VTC Spring), 2017, pp. 1–5. doi:10.1109/VTCSpring.2017.8108288.

[38] E. Bulut, M. C. Kisacikoglu, K. Akkaya, Spatio-temporal non-intrusive direct v2v charge sharing coordination, IEEE Transactions on Vehicular Technology 68 (10) (2019) 9385–9398. doi:10.1109/TVT.2019.2931954.

[39] C. Luo, Y.-F. Huang, V. Gupta, Stochastic dynamic pricing for ev charging stations with renewable integration and energy storage, IEEE Transactions on Smart Grid 9 (2) (2018) 1494–1505. doi:10.1109/TSG.2017.2696493.

[40] R. Alvaro, J. González, C. Gamallo, J. Fraile-Ardanuy, D. L. Knapen, Vehicle to vehicle energy exchange in smart grid applications, in: 2014 International Conference on Connected Vehicles and Expo (ICCVE), 2014, pp. 178–184. doi:10.1109/ICCVE.2014.7297538.

[41] A. Moradipari, N. Tucker, M. Alizadeh, Mobility-aware electric vehicle fast charging load models with geographical price variations, IEEE Transactions on Transportation Electrification 7 (2) (2021) 554–565. doi:10.1109/TTE.2020.3025738.

[42] O. S. Vaidya, S. Kumar, Analytic hierarchy process: An overview of applications, European Journal of Operational Research 169 (1) (2006) 1–29. doi:https://doi.org/10.1016/j.ejor.2004.04.028.
URL `https://www.sciencedirect.com/science/article/pii/S0377221704003054`

[43] A. Keränen, J. Ott, T. Kärkkäinen, The ONE Simulator for DTN Protocol Evaluation, in: ICST SIMUTools '09, Rome, Italy, 2009.

[44] [link].
URL `{https://www.helen.fi/en/electric-cars/charging-network}`

[45] [link].
URL `{www.codaautomotive.com.}`

[46] [link].
URL `{wheego.net.}`

[47] [link].
URL `{en.wikipedia.org/wiki/HyundaiBlueOn.}`