Intelligent Transportation Systems Enabled ICT Framework for Electric Vehicle Charging in Smart City

Yue Cao, Naveed Ahmad, Omprakash Kaiwartya, Ghanim Puturs, and Muhammad Khalid

Abstract In the future, Electric Vehicles (EVs) are expected to be widely adopted as personal, commercial, and public fleets in modern cities. The popularity of EVs will have a significant impact on the sustainable and economic development of urban city. However, compared to traditional fossil fuel vehicles, EVs have limited range and inevitably necessitate regular recharging. Thus, the provisioning of assured service quality is necessary for realizing E-mobility solution using EVs.

The design of an efficient charging management system for EVs has become an emerging research problem in future connected vehicles applications, given their mobility uncertainties. Major technical challenges involve decision-making intelligence for the selection of Charging Stations (CSs), as well as the corresponding communication infrastructure for information dissemination between the power grid and mobile EVs. This chapter introduces a number of information enabling technologies that been applied for EV charging, viewed from a transportation planning angle.

Keywords Electric Vehicle · Transportation Planning · Charging Management · Wireless Communication · Mobile Edge Computing · Vehicle-to-Vehicle · Mobility

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1 Introduction

The awareness concerning air pollution from CO2 emissions has increased in recent years, and the realization of a more environment-friendly transportation system is now a worldwide goal. The idea of applying Electric Vehicle (EVs) [1] as an alternative to fossil fuel powered vehicles is gaining lot of interest, while the research and development on EVs including battery design and charging methods have attracted the attention of both commercial and academic communities over the last few years.

Unlike numerous previous works [2] which investigate charging scheduling for EVs parked at home/Charging Stations (CSs), a recent focus has been on managing the charging scenario for on-the-move EVs, by relying on public CSs to provide charging services during their journeys. The latter use case cannot be overlooked as it is the most important feature of EVs, especially for replacing traditional fossil fueled vehicles for journeys. Here, CSs are typically deployed at places where there is high concentration of EVs, such as shopping malls and parking places. On-the-move EVs will travel toward appropriate CSs for charging based on a smart decision on where to charge (referred to as CS-selection), so as to experience short waiting time for charging.

In [3–5], the decision on where to charge is made by a Global Controller (GC) in a centralized manner. Here, the GC can access the real-time conditions of the CSs under its control, through reliable channel including wired-line or wireless communications. There is an issue regarding privacy, as the status of an EV, its ID, State of Charge (SOC) or location [6, 7] will be inevitably released, when that EV sends charging request to the GC. Also there is another issue regarding system robustness. This is because that the charging service will be affected by a single point of failure at the GC. Alternatively, the CS-selection could be made by individual EVs in a distributed manner, based on historically accessed CSs condition information recorded at the EV side. One example of this is provided in [8] where EVs will decide their preferred CSs for charging, based on gathered information from Road Side Units (RSUs).

To make the best CS-selection decision making system, necessary information (such as the expected waiting time at individual CSs) needs to be disseminated between CSs and EVs. In this context, the accuracy of CSs condition information is used for managing EV charging, this plays an important role on the charging performance. Indeed, it is important to position appropriate information dissemination infrastructure to support data exchange between the EVs and power grid. In literature, the cellular network communication (it is normally assumed with ubiquitous communication range) is applied in centralized manner. Meanwhile network entities associated in Intelligent Transportation Systems (ITS) can also help to decentralize the CS-selection decision making, from the centralized GC to localized ITS entities.

2 Related Work for CS-Selection

2.1 EV Charging in "On-the-Move" Mode

As noted by the most recent survey [9], fruitful works in literature have addressed "charging scheduling" [2] (the "Parking Mode"), by regulating the EV charging, such as minimizing peak load/cost, flattening aggregated demands or reducing frequency fluctuations.

In recent few years, the "CS-selection" problem (or say the "On-the-move" Mode) has started to gain interest, from industrial communities thanks to the popularity of EVs. The works in [3–5] estimate the queuing time at CSs, such that the one with the minimum queueing time is ranked as the best charging option. The work in [3] compares the schemes to select CS based on either the closest distance or minimum waiting time. In [10], the CS with a higher capability to accept charging requests from on-the-move EVs, will propose its service with a higher frequency, while EVs sense this advertisement with a decreasing function of their current battery levels. The CS-selection scheme in [11] adopts a pricing strategy to minimize congestion and maximize profit, by adapting the price depending on the number of EVs charging at each time point.

In addition to above works that consider local status of CSs, reservation-enabled CS-selection schemes bring anticipated EVs mobility information (reservations) to estimate whether a CS will be overloaded in a near future. For example, the work in [12] concerns a highway scenario where the EV will pass through all CSs. Other works under the plug-in charging service [5, 13–15] focus on city scenario.

2.2 Urban Data in Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) can fundamentally change urban lives at many levels, such as less pollution, garbage, disposal, parking problems and more energy savings. Exploring big data analytics via ubiquitous, dynamic, scalable, sustainable ecosystem offers a wide range of benefits and opportunities. Most of the techniques require high processing time using conventional methods of data processing. Therefore, novel and sophisticated techniques are desirable to efficiently process the big data generated from the stakeholders, in a distributed manner through ubiquitously disseminated and collected information. This will help to understand the city wide application in a whole picture.

Dedicated authorities should carefully consider which indicators were meaningful or how they should be analyzed. Here, the charging strategy in "On-the-move" Mode certainly benefits from analytics of data from CSs and EVs (that ideally should be captured ubiquitously and timely):

- CS's location condition refers to number of EVs being parked, with their required charging time [8]. A longer service queue implies a worse Quality of Experience (QoE) for incoming EVs, as they may experience additional time to wait for charging.
- Charging reservation at CS indicates which CS to charge. This includes the EV's arrival time, and expected charging time upon arrival at that CS.
- Trip destination refers that EVs would end up with journeys. Inevitably, selecting a CS that is far away from the drivers' trip destination would lead to a worse user QoE.
- Traffic condition on the road affects the EV's arrival time at CS, and energy consumed at that CS. The EV located within a certain range of traffic congestion will have to slow down its speed, whereas it will accelerate the speed once leaving from the range of traffic congestion.

2.3 Communication Technologies in ITS

ITS applications make use of wireless communications, including communications between vehicles, and between vehicles and fixed roadside installations with single-hops or multiple hops network links. Today's vehicles are no longer stand-alone transportation means, due to the advancements on Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications, to access the Internet via recent technologies in mobile communications including WiFi, Bluetooth, 4G, and even 5G networks. The connected vehicles are aimed towards sustainable developments in transportation by enhancing safety and efficiency. Apart from the synchronous point-to-point communication, the topic based asynchronous communication pattern publish/subscribe (P/S) has also been investigated.

2.4 Scalability of Charging System

The CS-selection problem could be solved in different ways including:

- The centralized approach relies on a cloud based GC to advance the resource efficiency, by taking the advantage of potential economies of scale. This brings much privacy concern, as EV status (e.g., location and trip destination) included in charging request will be released to the GC.
- The decentralized approach provides a better privacy protection, where the charging management is executed by the EVs individually. This alleviates the computation burden of centralized cloud server, by using the localized information at EV to make CS-selection.
- However, the computation capability run by distributed decision makers maybe insufficient; instead, a hybrid way is desirable to enhance the computation robust-

ness, by shifting the computational extensive tasks to GC. While the network edges which are closer to EVs, would process basic information aggregation and mining tasks. The EVs thus make CS-selection decision using information obtained from RSUs.

In the following sections, we introduce recent advances on EV charging systems with their enabling ICT technologies.

3 Centralized Charging System

3.1 Cellular Network Communication Enabled Charging System

In most of previous works, the decision on where to charge is generally made by a GC in a centralized manner. Here, the GC can access the real-time conditions of the CSs under its control, through reliable channel including wired-line or wireless communications, e.g., cellular network 3G/4G. This supports a ubiquitous and low delay interaction between EVs and GC.

Previous work [5] proposes a reservation-based EV charging scheme that periodically updates the charging reservation. Due to the traffic jam, the EVs' reservation (the arrival time at the CS, as well as the electricity consumption for travelling towards that CS) can be influenced by varied moving speed. Without reservation updating, an on-the-move EV may not reach a CS at the time it previously reserved, whereas the GC still has an obsolete knowledge that EV will reach on time. As such, the estimation on how long an incoming EV will wait for charging, is affected by the accuracy of the reservation information due to mobility uncertainty.

Based on Fig. 1, a typical procedure for our proposed EV charging management scheme is listed as follows:

- **Steps 1–2:** When an on-the-move EV needs charging service, namely EV_r, it contacts the GC with its charging request (including SOC, location, trip destination). The GC decides the appropriate CS to serve charging request (in terms of the minimized trip duration through an intermediate charging), and the decision is sent back to EV_r.
- **Steps 3:** EV_r reports its charging reservation in relation to its selected CS, including its arrival time, expected charging time and parking duration at the CS.
- **Steps 4:** When travelling towards a selected CS, EV_r periodically checks whether that CS currently selected is still the best choice, by sending a reservation update request to the GC.
- **Steps 5:** The GC then compares a cost in relation to the newly selected CS as well as that of previously selected CS. If charging at the previously selected CS cannot yield the minimum trip duration, the GC will inform EV_r about an updated arrangement with a new CS-selection.

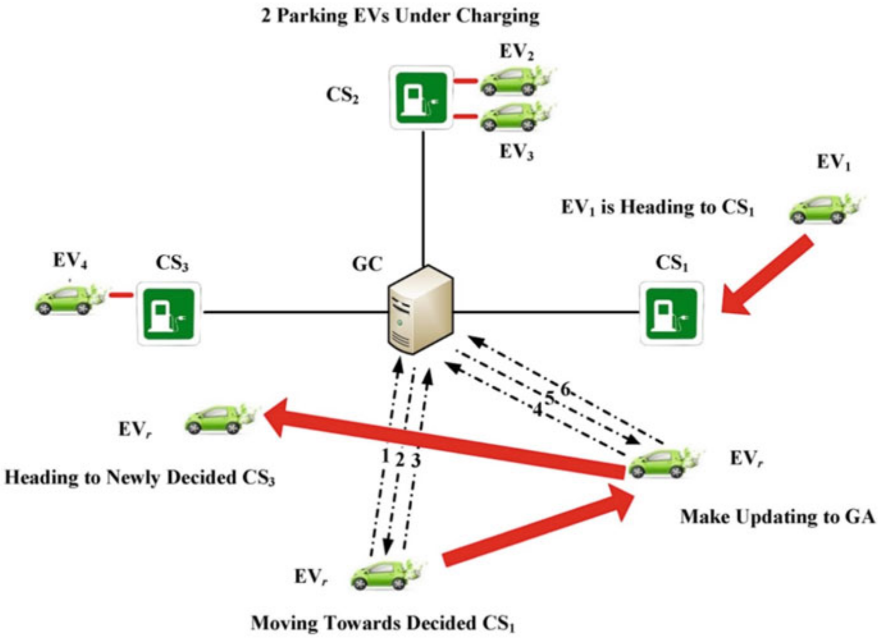


Fig. 1 Overview of reservation updating enabled EV charging

- **Steps 6:** EV_r thus cancels its reservation at the previous CS, and reports the updated reservation with the newly selected CS. Finally, EV_r changes its movement towards the location of the newly selected CS.

Steps 4–6 are repeated until EV_r reaches the newly selected CS for charging. Note that such new arrangement may change several times, depending on the frequency of reservation updating requests to trigger the computing logic detailed in [5].

3.2 *Enabling Internet of EVs for Charging Reservations Relay*

It is worth noting that reporting EVs' charging reservations (deemed as an auxiliary service), is delay-tolerant (as the essential charging recommendation system still works, even without reservation) and independent of charging request/reply. The 3G/LTE is applied due to its ubiquitous communication deployment. However, this ubiquitous communication comes at a cost and may not be needed all the time. This is because the charging reservations are only generated when EVs need charging.

Recently, the Vehicle-to-Vehicle (V2V) communication is receiving increasing interest, thanks to the inexpensive wireless connections and flexibility of installation on vehicles. Most of the problems in Vehicular Ad hoc NETworks (VANETs) arise from highly dynamic network topology, this results in the communication disruption along an end-to-end path towards destination. Here, the Delay/Disruption Tolerant Networking (DTN) [16] based routing protocols provide a significant advantage, by relying more on opportunistic communication to relay EVs' charging reservations. However, the delay due to opportunistic communication certainly has influence, on how accurate the reservation information is applied by the GC to make CS-selection decisions. E.g., a decision making based on the obsolete information that is due to long delay, may mislead the EV towards a CS in charging congestion. Envisioning for VANETs consisting of EVs, previous work [17] studies the feasibility to take the advantage of opportunistic V2V communication, mainly for the delivery of EVs' charging reservations in a multi-hop way.

When using the V2V communication, the communication cost certainly depends on the number of EVs (as explored in [18]). Whereas the communication cost when using the cellular network communication depends on the number of charging reservations. In other words, the former case is affected by the EVs density, whereas the latter case is affected by the number of service requests.

4 Distributed Charging System

4.1 V2I Communication Enabled Charging System

In spite of above advanced feature facilitating the charging reservation, the centralized system has issue from privacy aspect as aforementioned in [6, 7], when that EV sends charging request to the GC. Also, concerning system robustness, the charging service will be affected by the single point of failure at the GC side. Alternatively, the CS-selection could be made by individual EV in a distributed way, or the CS-selection decision making is operated by each EV locally.

Many previous works have adopted cellular network, where the application of ITS is also of importance for the future connected vehicles. Strategically deployed Road Side Units (RSUs) can support information dissemination as used by EV charging operations, through the Vehicle-to-Infrastructure (V2I) communication. Considering the V2I communication has been mature in existing VANETs, it is worth noting that the charging system will necessitate wireless V2I communication for EV charging perspective in addition to road safety perspective. Of course, how to realize RSU functions has been discussed in many previous works [19].

In order to enabling the distributed charging management, in [8] the RSUs are introduced as an intermediate entity. They can bridge the information flow exchange between EVs and the grid infrastructure CSs, through the wireless communication technologies. The actual realization of RSUs can be based on existing wireless communication technologies, such as cellular base stations or WiFi access points. It is worth mentioning that different realization of RSUs (in particular the radio transmission coverage) would affect the actual charging information, due to the

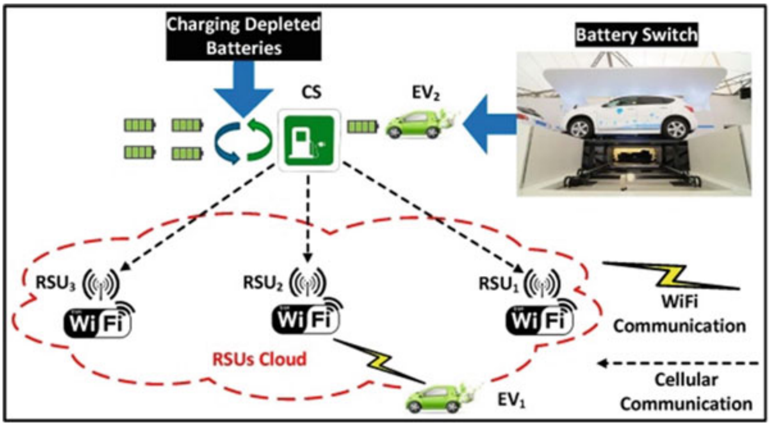


Fig. 2 V2I enabled communication network for battery switch

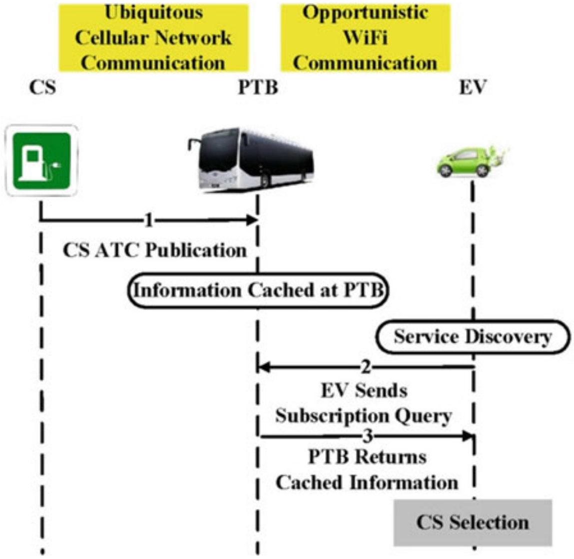
information freshness related to the data exchange between EVs and the grid. The battery switch based charging system [20] is further conducted based on this V2I communication network (Fig. 2).

4.2 V2V Communication Network Enabled Charging System

In the context of new communication technologies especially for smart transportation and autonomous cars, new mechanisms have been proposed in connected vehicle environments including V2I and V2V communications. On the one hand, V2I based approaches suffer additional costs to deploy and maintain dedicated stationary infrastructures, and additionally they suffer from rigidness due to the lack of flexibility of deploying and possibly relocating fixed RSU facilities. In comparison, the V2V based approach [13] is a more flexible and efficient alternative, this supports necessary data dissemination between connected vehicles when they encounter each other.

Due to high mobility, it is difficult to maintain a contemporaneous end-to-end connection (through a synchronous communication, e.g., unicasting, multicasting etc) between the CS and EV through Public Transportation Bus (PTB). The P/S communication framework is based on caching the CS condition at PTB. Here, the previously published CS condition information can be cached at intermediate PTBs. Whenever there is a future encounter between a pairwise PTB and EV, the EV can access the cached information by sending a query.

Fig. 3 Signalling flow of V2V communication network with PTBs



4.2.1 Basic Charging System without Supporting Charging Reservation

The P/S communication framework envisioning for EV charging scenario (with PTBs to relay information) is introduced as follows, with the time sequences illustrated in Fig. 3:

- **Step 1**: Each CS periodically publishes its condition information, e.g, Available Time for Charging (ATC) using the "*ATC Update*" topic defined in Table 1, to all the designated PTBs (that are involved in message dissemination in the P/S system) through the cellular network communication. In order to make efficient usage of the cellular link equipped at the PTB side, the PTB will aggregate the information in relation to each CS, as illustrated in the payload of topic. Then the aggregated information about all CSs condition is cached in the storage of PTB. Similar to the V2I based communication framework, once a new value has been received depending on CS publication frequency, it will replace the obsolete values in the past, which are not necessarily maintained.
- **Steps 2–3**: Given an opportunistic encounter between pairwise EV and PTB, the EV could discover whether the PTB has a service to provide CSs condition, based on existing service discovery, e.g., the location based scheme [21] proposed for VANETs. Then the EV sends an explicit query to the PTB, via the same topic through WiFi communication. Upon receiving this query, that PTB then returns its latest cached CSs condition information to that EV. With this knowledge, an EV requiring charging service can make its own decision on where to charge.

Under the city scenario, each public PTB is as an intermediate entity for bridging the information flow from CSs to EVs. Note that, in Fig. 3, the role of opportunistic

Table 1 Topic of "*ATC update*"

Topic name	Dissemination Mode	Publisher	Subscriber	Payload
ATC update	Many to Many	CSs	EVs	<"CS-1 ID", "Publication Time Stamp", "CS-1 ATC">
				<"CS-2 ID", "Publication Time Stamp", "CS-2 ATC">
				<"CS-3 ID", "Publication Time Stamp", "CS-3 ATC">
				<"CS-4 ID", "Publication Time Stamp", "CS-4 ATC">

WiFi is effectively used as the default radio communication technology, to enable the short-range communication between EVs and their encountered PTBs for information dissemination operations. This can be envisioned for the real-world application, where PTBs providing WiFi communication (already been applied in real world bus system), behave as mobile access points for information dissemination.

4.2.2 Reservation Based Charging System

Upon above generic framework, the EV which has made its CS-selection further sends its charging reservation (including when to reach and how long its expected charging time will be at the selected CS). Apart from the information flow relayed from the CSs to EVs in Sect. 4.2.1, the charging reservation will be relayed from the EV to its selected CS, also through opportunistically encountered PTBs.

With anticipated EVs' reservations, the charging plans of EVs can be managed in a coordinated manner. For example, if a CS has been reserved by many on-the-move EVs for charging, that CS predicts and publishes its status associated with a near future. Other EVs need charging services would identify the congestion status of CS, and thus select an alternative CS for charging purpose to avoid the congestion. Here, the CS-selection policy based on the Expected Earliest Time Available for Charging (EETAC) published from CSs, is to find the CS at which the EV would experience the shortest charging waiting time.

In Fig. 4, a typical procedure is illustrated as follows:

- **Steps 1–3**: These steps are still executed through the procedure in Sect. 4.2.1. Note that the information disseminated (e.g., the EETAC through topic "*EETAC Update*" topic in Table 2) is different from the ATC involved in Sect. 4.2.1.
- **Steps 4–5**: Based on accessed information, any EV requiring charging service can make its own decision on where to charge, and further publishes its charging reservation to any encountered PTB. Here, each PTB as subscriber

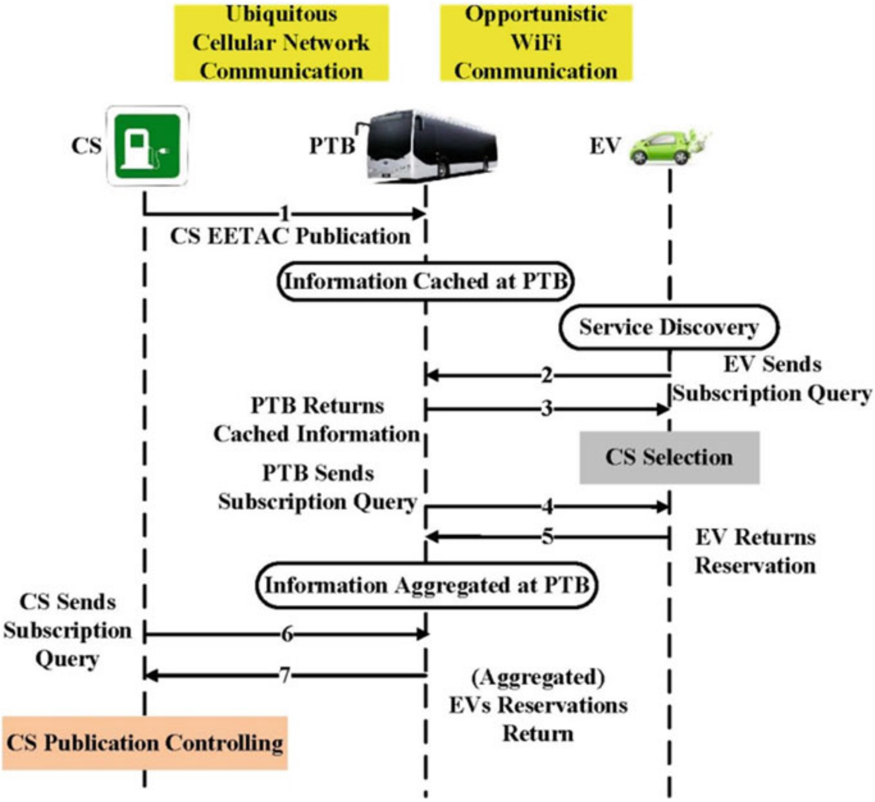


Fig. 4 Signalling flow of charging system via PTB network

Table 2 Topic of "*EEATC update*"

Topic name	Dissemination Mode	Publisher	Subscriber	Payload
EETAC update	Many to Many	CSs	EVs	<"CS-1 ID", "Publication Time Stamp", "CS-1 EETAC">
				<"CS-2 ID", "Publication Time Stamp", "CS-2 EETAC">
				<"CS-3 ID", "Publication Time Stamp", "CS-3 EETAC">
				<"CS-4 ID", "Publication Time Stamp", "CS-4 EETAC">

sets a "*Reservations Aggregating*" topic defined in Table 3, and subscribes to the reservations from encountered EVs. The number of such topics depends on number of PTBs, as each PTB uses its individual topic to collect EVs' reservations.

Table 3 Topic of "*Reservation aggregating*"

Topic name	Dissemination Mode	Publisher	Subscriber	Payload
Reservations aggregating	Many to One	EVs planning charging	PTBs	EVs' charging reservation

Table 4 Topic of "*Aggregated reservations collection*"

Topic name	Dissemination Mode	Publisher	Subscriber	Payload
Aggregated reservations collection	Many to One	PTBs	CS	<Next time stamp for CS publication, aggregated EVs' charging reservations

- **Steps 6–7**: At the CS side, it accesses aggregated EVs' reservations through the "*Aggregated Reservations Collection*" topic defined in Table 4. The number of this topics depends on number of CSs, as aggregated reservations are in line with an explicit CS. Note that all aggregated EVs' reservations (in relation to an explicit CS) stored at PTBs should be published to that CS, before its next publication time stamp as given by $(X + T)$. Recalling that X is the time stamp for previous CS publication, while T is the CS publication frequency. Such information triggers all PTBs connected (through cellular network communication) with an explicit CS, to publish their aggregated EVs' reservations related to that CS. The CS computes its updated EETAC and releases at next publication time slot.

5 Hybrid Charging System

5.1 V2I Communication Network Enabled Charging System

In [14], a hybrid charging system is designed based on V2I communication. All CSs periodically publishes its Available Time for Charging (ATC) to RSUs. Furthermore, EVs are capable of making remote reservations to the GC through RSUs, before reaching their selected CSs. The GC then analyzes the EVs' charging reservations together with their associated CS's local condition information, to compute and notify ATC publication of that CS. The GC also schedules the amount of electricity among CSs, depending on the anticipated charging demands (identified from received EVs' charging reservations) (Fig. 5).

The system designs a closed control loop to adjust a time window within which the prediction is valid, via the analytics of EVs arrival time. Therefore, the sooner EVs will approach CSs for charging, a much tight time window should be determined for prediction and vice versa. Besides, the aggregation at RSUs benefits to communication cost involved for reservation reporting within system.

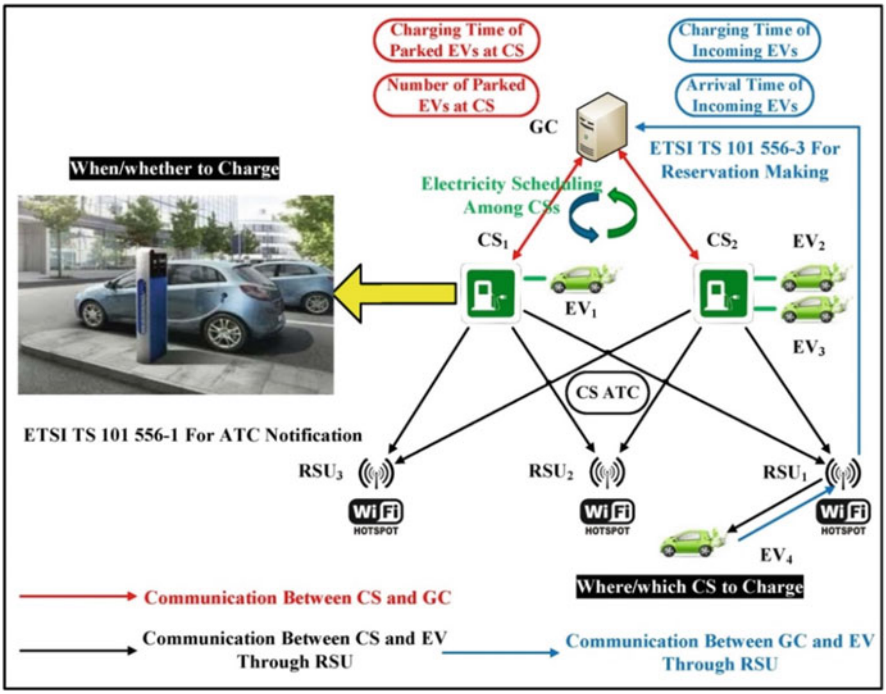


Fig. 5 Overview of hybrid charging system of V2I communication network

The "ETSI TS 101 556-1" [22] standard has been defined for the on-the-move EV charging use case. Its basic application is to notify EV drivers about the CSs' status (e.g., ATC), such that EVs are able to select CSs for charging. In addition, the "ETSI TS 101 556-3" [23] standard enables the remote charging reservation service, from EVs to the GC. Figure 6 shows a typical procedure:

- **Step 1**: Each CS periodically (with publication interval *T*) publishes its ATC to all RSUs, using its individual "*ATC Update*" topic (defined in Table 5). The RSU subscribes to the publications from all CSs, will aggregate and cache their ATC information.
- **Steps 2–3**: Given an opportunistic encounter between pairwise EV and RSU, the EV fetches the cached information from that encountered RSU. Here, the EV is aware of an updated service published from RSU (through existing service discovery protocols). As such, it only subscribes to the aggregated ATC of CSs, which is published at updated time slot using the "*Aggregated ATC Update*" topic. This reduces the redundant access signalling, particularly when the EV frequently encounters several RSUs in a short time.
- **Step 4**: The EV requiring charging service can make its own CS-selection decision on where to charge, and further publishes its charging reservation to an encountered RSU. Here, the "*Charging Reservations Report*" topic is applied,

Table 5 Topics of hybrid charging system with V2I communication network

Topic	Dissemination nature	Publisher	Subscriber	Payload
ATC update	One-to-Many	CS	RSUs	<CS ID, CS's ATC, publication time slot>
Aggregated ATC update	Many-to-Many	RSUs	EVs	<Aggregated CS IDs and CSs' ATC, publication time slot>
Charging reservations report	Many-to-Many	EVs planning charging	RSUs	<EV ID, arrival time, expected charging time>
Aggregated charging reservations report	Many-to-One	RSUs	GC	<Aggregated EVs' reservations cached by RSUs>
Local condition update	Many-to-One	CSs	GC	<CS's local condition information, including number of EVs parking at CS and their charging time>
ATC controlling	One-to-Many	GC	CSs	<Computed ATC of each CS>

with the EV as publisher and RSUs as subscribers. Each RSU aggregates its received EVs' charging reservations and locally caches it.

- **Steps 5–6**: At the GC side, it sets two dedicated topics to collect information from CSs and RSUs. Rather than seamless operation (real-time monitoring), such collection task is only operated when the next time slot for CSs' publication is approaching. The local condition information of CSs includes the number of EVs been parked and their required battery charging time, which is accessible by sending a subscription query via the "*Local Condition Update*" topic. The GC also accesses aggregated EVs' charging reservations from all RSUs, using the "*Aggregated Charging Reservations Report*" topic.
- **Step 7**: The GC then computes the ATC related to each CS, and controls their publication at the next time publication interval, using the "*ATC Controlling*" topic.

Compared to [13], this work brings heterogeneous topics illustrated in Table 5 and enables light-weight computation at RSUs side. If using single topic for publication, there is no information merged at RSUs. In that case, an EV needs to use different subscription topics (associated to a CS) to access all CSs information from RSUs, particularly when CSs are owned by different stakeholders. In comparison, all merged CSs information at RSUs can be subscribed by an EV with unique topic. Each RSU can further verify the information of CSs and authorized information for caching, meanwhile check the time slot involved in the EV subscription.

In this system, the communication cost at CS side for information dissemination is given by $O\left(\frac{N_{rsu}}{T}\right)$, since there are only N_{rsu} subscribers within each T interval.

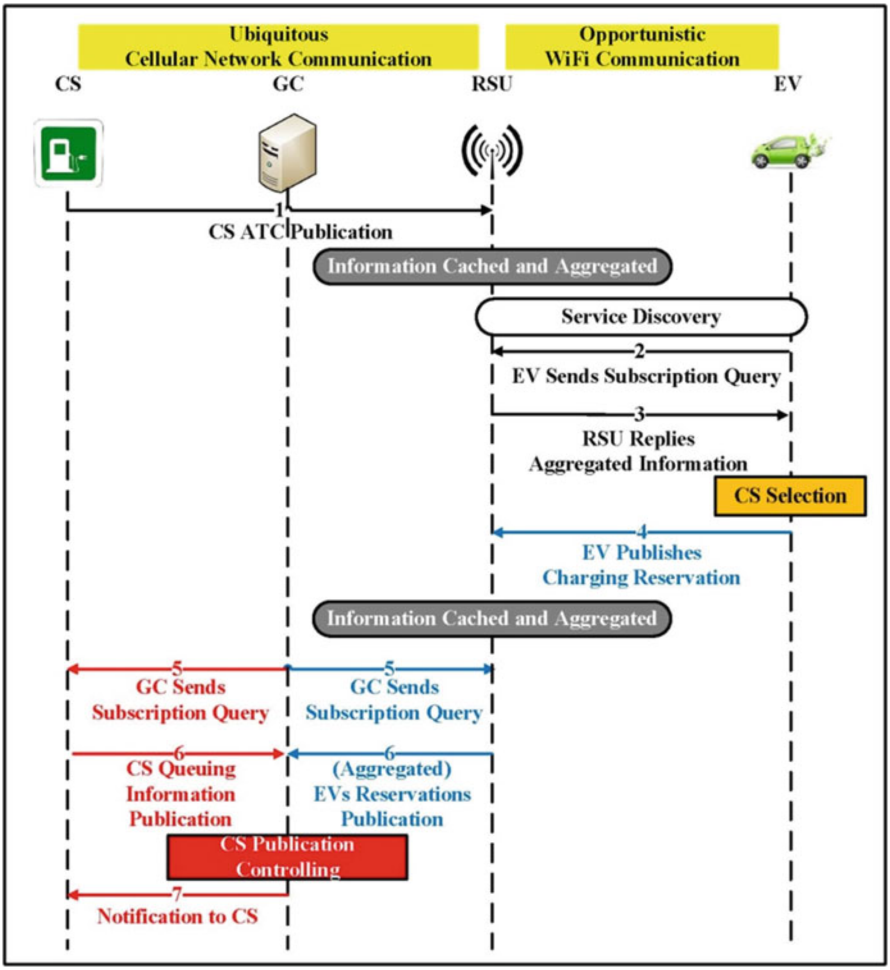


Fig. 6 Signalling flow of hybrid charging system with V2I communication network

Similarly, the cost for reservations making to the GC is given by $O\left(\frac{N_{rsu}}{T}\right)$, owing to the information aggregation at RSUs. In comparison, the centralized system is with cellular network communication, the cost at GC side for handling EVs' charging requests and charging reservations are both $O(N_{ev})$.

In reality, it is reasonable that ($N_{rsu} \ll N_{ev}$), while the number of charging services is larger than N_{ev} (meaning that each EV needs to charge more than once in long term). As such, the efficiency and scalability of hybrid system is achieved. Having no direct communication between service providers and clients, this system also alleviates the attack surface of network entities.

5.2 V2V Communication Network Enabled Charging System

The rapid growth of Internet of Vehicles (IoV) applications have placed severe demands on cloud infrastructure, which has led to moving computing and data services towards the edge of cloud, resulting in a novel Mobile Edge Computing (MEC) [24] architecture. MEC could reduce data transfer times, remove potential performance bottlenecks, and increase data security and enhance privacy while enabling advanced applications such as smart functioned infrastructure. The major difference between cloud computing and MEC, is on the location awareness to support application services (Fig. 7).

This is because the cloud server [25] normally locates in a centralized place, behaves as a centralized global manager to compute tasks (with information collected ubiquitously). Note that, MEC servers at different locations [26] are owned and managed by separate operators and owners. With the collaboration among different operators, they can form a collaborative and decentralized computing system in the wide region.

The work in [15] further extends the hybrid charging system with V2X communication network enabled, by using PTBs while with a discussion on potential of Unmanned Aerial Vehicles (UAVs). Basically, UAV are flying aircrafts which can either be controlled remotely or autonomously. Despite the fact that relatively large UAV platforms are playing increasingly prominent roles in strategic and defense programs, technological advances in the recent years have led to the emergence of smaller and cheaper UAVs.

Even though RSUs have been widely applied in VANETs, the deployment introduces additional economy cost. In addition to deployment cost, effectiveness and utilization of RSUs may also depend on the number of EVs that are presented in a given area. Although applying PTBs envisions for a more flexible way than RSUs, the bus mobility limited by regulated routes (only covers majority areas of a city) may degrade the coverage of information dissemination. Even if the mobility of UAVs is not limited by any route, the energy constraint is a primary concern for operating a large number of UAVs, where the interaction between UAVs and EVs leads to massive network overhead and can eventually undermine the UAVs' energy (thus its average lifetime). Inevitably, to frequently recharge UAVs degrades the network connectivity.

6 Further Discussions

6.1 Energy Sustainability

The wide spread of EVs experienced in recent years, must be accompanied by sufficient grid infrastructure deployment. The mismatch between EVs and infrastructures would potentially hinder the popularity of EVs. With the ever increasing

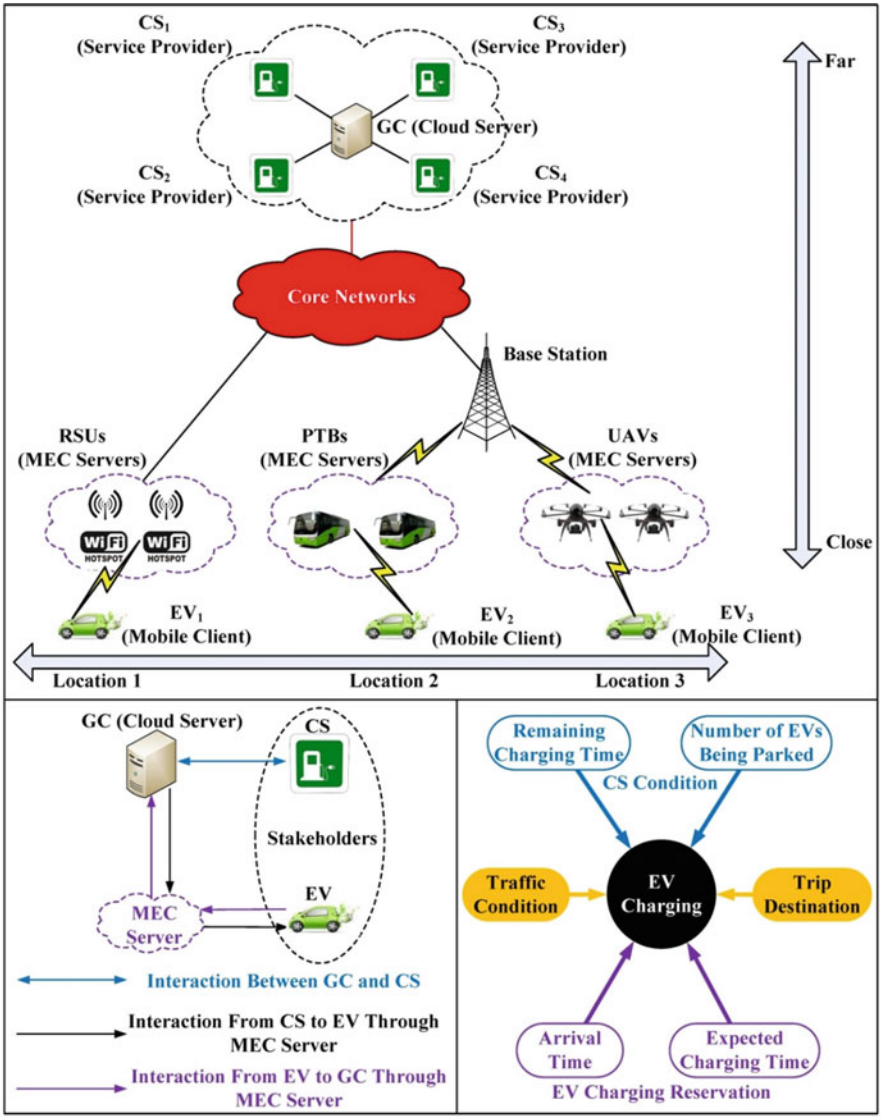


Fig. 7 Overview of MEC supporting EV charging

penetrations in EVs, the resultant charging energy imposed on the electricity network could lead to grid issues, such as voltage limits violation, transformer overloading, and feeder overloading at various voltage levels. The charging coordination with renewable energy source provides a more straightforward approach, to cope with the potential network issues. For example, the generation profile from photovoltaic coincides with the usage pattern and therefore charging profile of public charging stations.

Besides, the engagement of Vehicle-to-Grid (V2G) adapts charging points to have the capability for bidirectional power flow. With appropriate control and communication with the grid, EVs could be designed to operate as part of a “grid”, and this helps to provide supply/demand matching for energy sustainability.

6.2 Data Analytics

The sustainability of EVs requires a fundamental study on data analytics on how/whether/which drivers are desirable to switch from fossil fueled vehicles to EVs. This requires the human centric data related to their routine, finance to predict and educate drivers regarding switch benefit. Also, the driving pattern of EVs will be important to guide with optimal deployment of charging infrastructures.

6.3 Security and Privacy

The solution to achieve trustful messages exchange is to encrypt the sensitive information and hide the real identity. One development of the encryption involves the light-weight and highly secured encryption scheme, while another one is to design an efficient and scalable key management scheme. As for the privacy side, pseudonym is proposed to hide the identities. This includes the pseudonym changing algorithms and pseudonym reuse schemes, and both should be implemented in efficient and scalable manners. The future challenges are considered based on the nature of large number of connected EVs, high mobility, wide coverage area, heterogeneous communication systems. Security and privacy schemes will have the abilities of little bandwidth resources consumption, large number node supportable and short processing time.

7 Conclusion

This chapter reviewed a number of up-to-date literature works which study the integration of ICT with EV charging. The optimization problem is scaled from transportation angle, which aims to minimize the charging waiting time. The centralized, distributed and hybrid systems in line with cellular network, V2I&V2V communication networks have been presented and integrated into EV charging systems. In summary, the centralized charging system relies on the GC to handle charging requests from EVs, and to make decision on which CS that should EV plan for charging. In the distributed charging system, each EV could make their individual decisions for CS-selection, where the RSUs and PTBs are applied to bridge the information publication from CS to EVs. The hybrid charging system facilitates the computation advance of GC to predict and control the information dissemination in network. Meanwhile, it shifts the light-weight computation at network edge for information caching and mining to help EV for CS-selection decision making.

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