# Vehicular-Publish/Subscribe (V-P/S) Communication Enabled On-the-move EV Charging Management

Yue Cao, Ye Miao, Geyong Min, Tong Wang, Zhiwei Zhao and Houbing Song

***Abstract*—Recently, the charging management for Electric Vehicles (EVs) on-the-move has become an emerging research problem in urban cities. Major technical challenges here involve intelligence for the selection of Charging Stations (CSs) to guide drivers' charging plans, as well as the corresponding communication infrastructure for information dissemination between the power grid and EVs. In this article, a Vehicular-Publish/Subscribe (P/S) communication framework, in conjunction with Public Transportation Buses (PTBs) is provisioned to support on-the-move EV charging management. Benefiting from low privacy sensitivity, we propose a fully distributed charging management scheme concerning the driving intention. Results demonstrate a guidance for the provisioning of V-P/S communication framework, concerning EV drivers' experience including charging waiting time and total trip duration. Also, the benefit of V-P/S communication framework is reflected in terms of the communication efficiency. Open research issues of this emerging research area are also presented.**

## I. Introduction

The awareness concerning air pollution from $CO_2$ emissions has increased in recent years, and the attention towards a more environmentally friendly transportation system is now a worldwide goal. As an alternative to fossil fuel powered vehicles, Electric Vehicle (EVs) [1] have been brought to global market thanks to zero emissions of carbon dioxide. However, EVs on-the-move are more likely to run out of energy, thus need to recharge batteries during their journeys. This is mainly due to the limited battery capacity and long trip distance in urban cities. Therefore, how to manage the charging process to improve EV drivers' comfort, is vital to the success and long-term viability of EV industries.

The idea of EV charging management has been investigated: The *Parking Mode* addresses the use case where EVs are parking at homes/Charging Stations (CSs), with the concerning on when/whether to charge EVs. The *On-the-move Mode* addresses the use case where EVs are on-the-move, with the concerning on where to charge EVs. As EVs will become more prevalent, their charging demands will significantly rise. As such, there is a necessity to design the communication infrastructure with efficiency and sustainability in mind. In this article, we investigate how to efficiently manage the on-the-move EV charging in urban cities. Specifically, we aim to answer the following three questions:

- How can state-of-the-art Intelligent Transportation Systems (ITS) techniques be utilized for EV charging management, e.g., Public Transportation Bus (PTB), Global Position Systems (GPS), standardization of Vehicle to Vehicle (V2V) communications?
- Which CS should be selected by the EV driver to achieve the best driving experience (e.g., minimized charging waiting time and trip duration), and what is the impact of urban driving intention on the charging management process?
- How does the provisioning of ITS-enabled V2V communication framework affect the actual driving experience, and what is the benefit of this V2V communication framework?

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To answer above questions, we first present a review on existing EV charging management. Then, we propose a Vehicular-Publish/Subscribe (V-P/S) communication framework to facilitate the fast charging service, where necessary information (charging availability of CSs) are shared among different EVs and other ITS entities such as PTBs. We further propose a distributed charging management scheme concerning users' driving intention, and evaluate it through realistic simulations based on the map of Helsinki city.

## II. Review on EV Charging Management

### A. Parking Mode

Majority of previous works have addressed this use case (concerning when/whether to charge EVs), where EVs have already been parking at homes/CSs. For a detailed survey of this use case, we recommend the readers to refer to [2]. Here, we briefly summarize these works as follows:

- Schedule and control the charging/discharging of EVs, with different durations such that power grid constraints are maintained. This benefits power grid such that peaks and possible overloads of the electricity network may be avoided.
- Address pricing issue in order to encourage EVs not to charge during periods of high demand.
- Integrate renewable energy, mainly solar and wind into grid as complimentary solution, from which sustainable energy could be provided to support massive demands.

### B. On-the-move Mode

A few works have been studied to manage the EV drivers' charging plans where they are on-the-move, including:

- Route EVs (with charging event [3]) to minimize energy loss and maximize energy harvested during a trip, such that the time spent to fully recharge EVs is minimized. This would consider EV speed, as part of the efficiency of EVs results from their ability to recover some energy during deceleration.

- Where to deploy CSs (providing either plug-in charging or battery switch service [4]) such that EVs can access CSs within their driving ranges.
- Select the appropriate CS as charging plan (or refer to where to charge). For example, to select the CS which is not highly congested [5], so as to experience a minimized charging waiting time.

## III. Provisioning of V-P/S Communication Framework For On-the-move EV Charging Service

In this article, we focus on the latter use case, explicitly tackling where to charge EVs. Although a few existing works have addressed the charging management aspect, the attention towards an efficient communication framework has not received much attention.

### A. Centralized vs Distributed Charging Management

In general, the on-the-move EV charging management can be executed in both centralized and distributed manners.

- With the centralized manner, the charging management is executed by a Global Controller (GC) or other third party who is interested in charging management. However, this suffers from much privacy concern, because the EV status information (e.g., location, trip destination and ID) has to release to the GC.
- The distritbuted manner benefits from a low privacy sensitivity, where the charging management is executed by EV individually (via accessed condition information from CSs).

With both manners, necessary information needs to be disseminated to corresponding entities involved in charging management. The accuracy of information plays an important role on the charging management. In the worst case, the obsolete information would lead to a wrong CS-selection. In general, the cellular network communication (with a ubiquitous communication range) is applied for the centralized management manner. While heterogeneous network communications (e.g., WiFi, WiMAX or even Delay/Disruption Tolerant Networking (DTN) [6]) can be applied for distributed management manner.

### B. Vehicle-to-Vehicle/Infrastrucuture Communication

Up to now, new mechanisms have been proposed for reducing the information dissemination delay and improving the reliability for data transfer, via either Vehicle-to-Infrastructure (V2I) or Vehicle-to-Vehicle (V2V) communication. Existing work for on-the-move EV charging management has brought the fixed Road Side Unit (RSU) [5] for information dissemination. However, the V2I communication requires additional cost to deploy and maintain RSUs, and in particular it is limited in terms of practicality and stability to deploy RSUs on every intersection in Vehicular Ad hoc NETworks (VANETs). Also, how to optimally deploy RSUs is very rigid and inflexible.

Instead, thanks to the vehicle mobility bringing opportunistic communication that potentially expands the coverage of information dissemination, the V2V communication is a more flexible and viable alternative in near future. This enables real-time exchange of basic, anonymous based speed/location information, and provides crash avoidance capability between vehicles, buses and even pedestrians.

### C. The V-P/S Paradigm

Nevertheless, the dynamically changed network topology due to fast vehicle speed or sparse network density, results in frequent communication disruption. As such, vehicles are not always able to communicate with each other seamlessly. Here, the Publish/Subscribe (P/S) [7] paradigm, is a suitable communication paradigm for building applications in VANETs with a highly elastic and scalable nature.

Considering the EV charging application, the Vehicular-Publish/Subscribe for information dissemination, namely V-P/S, is also applicable where each CS as a publisher publishes its condition information (e.g., availability to provide charging service), to EVs as subscribers of the information. We exploit the predictable mobility of Public Transportation Buses (PTBs), for information dissemination in the P/S system. The advantage is that such mobile entities offer opportunistic encounters with EVs in charging requirement on the road. The flexibility of bringing PTBs may take into account a wide range of knowledge, e.g., bus routes[1], number of buses in service and also their service time intervals. Three network entities are involved in the V-P/S system:

- **Electric Vehicle (EV)** as subscriber, actively sends query to subscribe to the information relayed by PTBs. The EV is with a Status Of Charge (SOC). If the ratio between its current energy and maximum energy is below the value of SOC, the EV will start to select a CS as charging plan.
- **Charging Station (CS)** as publisher, is located at a certain location to charge EVs in parallel, based on multiple charging slots. Its condition information is periodically published to the legitimate PTBs.
- **Public Transportation Bus (PTB)** is a mobile entity to behave as broker, which aggregates all CSs condition information and caches it in local storage. The mobility of PTBs is restricted by their predefined routes, while PTBs may temporarily stop once their deterministic routes are traversed.

In Fig.1, each CS as publisher, publishes its condition information (availability to provide charging service), to EVs as subscribers of this information. Along with this, PTBs running on their dedicated routes execute P/S based information dissemination, through the V2V communication. The provisioning of such V-P/S communication framework well fits the distributed charging management manner, where EVs could access CSs condition information from opportunistically encountered PTBs (within the PTBs cloud to share all CSs condition information) and make their local charging management decisions. The PTBs cloud (number of PTBs and

[1]It is reasonable that a number of buses would run normal services at majority of the city routes. Since EV drivers could travel towards any place in a city, the diversity of bus routes certainly guarantees the chance for EVs to obtain information.

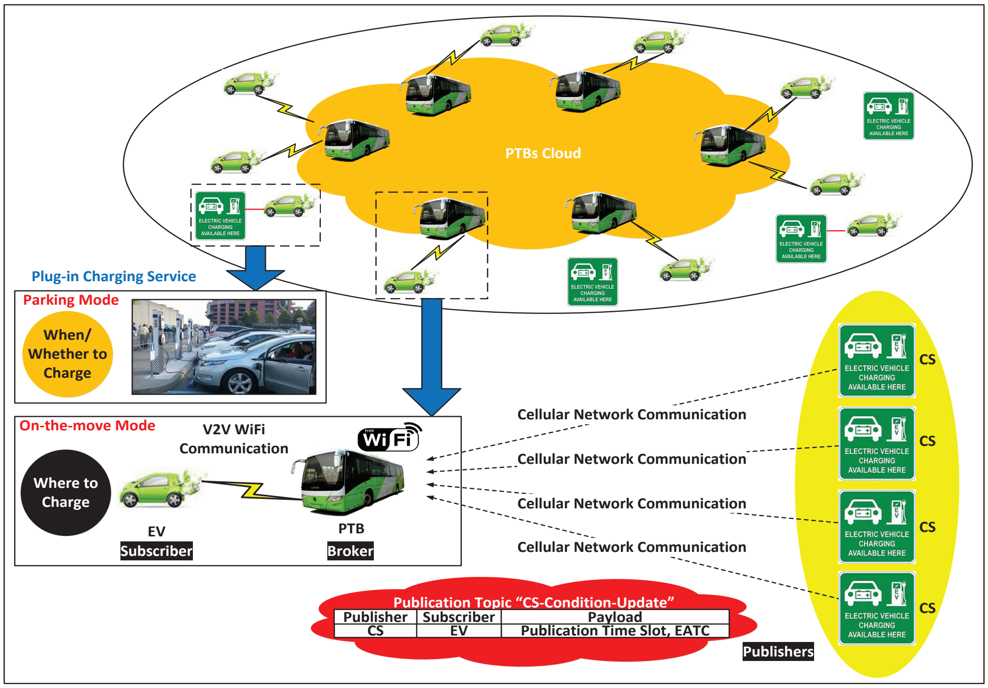



Fig. 1. Big Picture of On-the-move EV Charging Management Via V-P/S Communication Framework

those running on given routes) can be formed dynamically, depending on the fluctuated charging demands within certain urban areas.

### *D. The Design of V-P/S Communication Framework*

Envisioning for urban scenario, all CSs are geographically deployed and their locations are pre-known by all EVs. These locations are pre-stored in the On-Board-Unit (OBU) of EVs. Each CS is connected to all PTBs using reliable channel, such as authorized and licensed cellular network communication, and periodically publishes its condition information, e.g., the Earliest Available Time for Charging[2] (EATC).

As a type of public transportation, the number of PTBs is normally less than that of EVs. Due to high mobility, it is difficult to maintain a contemporaneous end-to-end connection between the CSs and EVs through PTBs. As such in the V-P/S communication framework, PTBs cache the aggregated information from CSs. Given an opportunistic encounter with a PTB and EV, the information can be accessed by EV, through sending a query to the PTB.

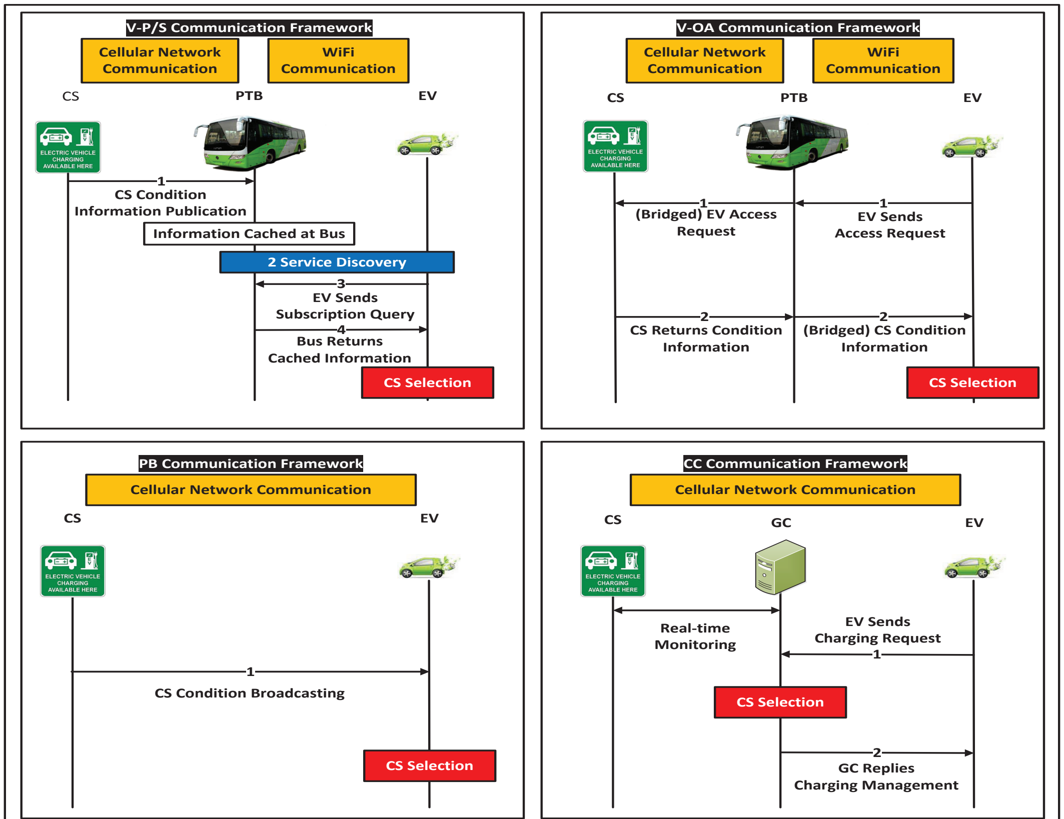
EVs with a low electricity volume will then decide where to charge, based on their accessed CSs condition information from PTBs. In particular, the credibility [8] of information from CSs is required for the hazard-free decision of EVs. Thus, all messages must be digitally signed by CSs and later can be verified by EVs before making their CS-selection decisions.

In [5], the “ETSI TS 101 556-1” [9] standard has been brought for a V2I based P/S communication framework, via RSUs for information relay. Its basic application is to notify EV drivers about the CSs condition information through strategically deployed RSUs, such that they are able to select CSs for charging. Here, it is potentially applicable for the V-P/S communication framework, where PTBs are owned by authorities which are trustable for CSs. The time sequences of V-P/S are illustrated in Fig.2:

- **Step 1:** Each CS periodically publishes its condition information, e.g., the Earliest Availability Time for Charging (EATC) using the topic “CS-Condition-Update”, to all the legitimate PTBs that are involved in information dissemination. Each PTB will aggregate the information published from all CSs, and then caches it in the storage. If a new information is received, the PTB will replace the obsolete one cached in the past, that is not necessarily maintained.
- **Steps 2:** Given an opportunistic encounter between pairwise EV and PTB, the EV could discover whether the PTB has such service to provide CSs condition, based on existing service discovery proposed for VANETs. In particular, the EV can be aware of updated services from PTBs, and thus only sends subscription query in relation to the information published at updated time slots. This reduces the redundant access signallings, particularly when an EV encounters several PTBs frequently.
- **Steps 3:** Using the same “CS-Condition-Update” topic for information access, the communication is established through a V2V enabled WiFi communication.
- **Steps 4:** When receiving the query, the PTB returns its cached CSs condition information to that pending EV. With this knowledge, the EV needs charging service can make its own CS-selection decision on where to charge.

We here present a simplified analysis on V-P/S. The Expected Meeting Time (EMT) of pairwise nodes (an EV

[2] It represents the earliest time that a charging slot (plug-in charger) at the CS is available.




| Compared Communication Frameworks | End-to-End Connection | Number of Connection at CS | Ubiquitous Communication | Privacy Sensitivity | Supported Charging Management Manner |
|---|---|---|---|---|---|
| V-P/S | Not Required | Low | Not Required | Low | Distributed |
| V-OA | Required | High | Not Required | Low | Distributed |
| PB | Not Required | High | Required | Low | Distributed |
| CC | Not Required | Low | Required | High | Centralized |

Fig. 2. Illustrations of V-P/S And Other Options

and PTB) are assumed to be Independent and Identically Distributed (IID) exponential random variables. It has been shown that a number of popular mobility models like Random WayPoint (RWP) as well as more realistic, synthetic models are based on such (approximately) exponential encounter characteristics [10]. Particularly, realistic VANETs mobility models already shown an exponential encounter rate between vehicles. Note that $EMT$ is driven by the entire network area and dedicated V2V communication range. We denote the CS information publication interval as $T$ (meaning how often CS publishes information), and number of PTBs as $N$.

We are interested in the possibility that an EV could access aggregated CSs condition information from at least one of $N$ PTBs in network. This depends on:

- Whether there is an encounter between EV and PTB.
- Whether an encountered PTB has cached the aggregated information published from CSs.

Given that there are $N$ buses in network, we summarize the possibility $P_{(v-p/s)}$ that an EV can access information from at least one of $N$ PTBs, as:

$$P_{(v-p/s)} = 1 - \prod_{i=0}^{N-1} \left(1 - \frac{EMT}{(N-i) \times T}\right) \tag{1}$$

Here, the possibility $\frac{EMT}{(N-i)\times T}$ that EV can access information from the $i^{th}$ PTB, depends on the CS publication interval $T$ (how frequent the CS publishes its EATC), and the encounter time $\frac{EMT}{N-i}$ between an EV and that PTB. Note that $\frac{EMT}{(N-i)\times T} = 1$ holds true, only when the encounter interval $\frac{EMT}{N-i}$ is longer than the CS publication interval $T$. Otherwise, $\frac{EMT}{(N-i)\times T} = 0$. As such, in order to increase $P_{(v-p/s)}$ through an appropriate communication framework provisioning, we obtain:

- To reduce CS publication interval $T$ (appropriate if with frequent CS information publication).
- To increase the number of PTBs $N$ (appropriate if with more opportunities for EVs to access information).

### *E. Other Alternative Options*

In Fig.2, we also present other three alternative options, namely **Vehicular-Opportunistic Access (V-OA)**, **Periodical Broadcasting (PB)** and **Centralized Case (CC)**.

***Vehicular-Opportunistic Access (V-OA):*** In this option, the access request from an EV is directly relayed by the encountered PTB to all CSs. Upon receiving the access request, all CSs reply their up-to-date condition information to the EV, also through that PTB. Note that, the EV may access the same condition information from CSs (as the status of those CSs does not change), when it encounters PTBs. This would bring additional communication overhead. Since there is no periodical CSs information publication, we obtain:

$$P_{(v-oa)} = 1 - \prod_{i=0}^{N-1} \left(1 - \frac{1}{N-i}\right) \quad (2)$$

Note that $(EMT \geq T) \Rightarrow \left(\frac{EMT}{T} = 1\right)$ already holds true for the analysis in V-P/S, we further obtain $P_{(v-p/s)} \leq P_{(v-oa)}$. This implies the performance of V-OA is the upper bound of V-P/S.

***Periodical Broadcasting (PB):*** This is a simple case where each CS periodically (with interval $T$) broadcasts its condition information to all EVs, also equivalent to the case where drivers use mobile phone to collect broadcasted CSs' information. The broadcasting is through the cellular network communication, and there is no PTB involved. As such, each EV can definitely access CSs condition information within interval $T$.

***Centralized Case (CC):*** Concerning the PB communication framework with an extremely short interval $T$, the PB would be equivalent to the Centralized Case (CC). This is because that, in the latter case the Global Controller (GC) monitors the instantaneous CSs condition, while the charging management is made instantly for each EV with charging request.

Fig.2 has also characterized the V-P/S and other three alternative options. Firstly, the V-OA achieves a higher information access possibility than the V-P/S. However, the former requires a contemporaneous end-to-end connection between CSs and EVs (through PTBs), and also brings more number of connections at the CS side. Secondly, although the PB does not need to involve PTBs, it however relies on a ubiquitous cellular network communication and broadcasting nature. This is even more expensive than the V-OA which utilizes a short range WiFi communication with an opportunistic nature. Thirdly, in sharp contrast to above three options, the CC is deemed as a high privacy sensitive system, in which the EV status information has to release.

## IV. On-the-move EV Charging Management Via The V-P/S Communication Framework

### A. Impact of Driving Intention on Charging Management

This refers to the situation that EV drivers have their daily routes or Point Of Interests (POIs), e.g., to visit shopping malls or public parks for leisure. Here, selecting a CS that is far away from the drivers' trip destination is user unfriendly, as the total trip duration through charging at a CS will be increased. As such, the driving intention would inevitably affect the CS-selection decision.

### B. System Cycle of On-the-move EV Charging Management

Fig.3 describes four phases within the on-the-move EV charging management cycle.

- **Driving Phase:** The EV is travelling towards its trip destination.
- **Charging Planning Phase:** The EV reaching a threshold on its residual battery volume applies a policy to select a dedicated CS for charging. Based on its locally recorded CSs condition information, the EV (with trip intention) locally runs the CS-selection logic.
- **Charging Scheduling Phase:** Upon arrival at the selected CS, the underlying charging scheduling concerning when to charge EVs, is based on the First Come First Serve (FCFS) order. This means that the EV with an earlier arrival time will be scheduled with a higher charging priority. Of course, further effort could be referred to those contributions paid for *Parking Mode* [2]. Here, tackling the number of EVs waiting for charging and their charging time are as inputs for computing the EATC of a CS.
- **Battery Charging Phase:** The EV is being charged via a plug-in charger at CS. Upon departure (fully charged), the EV turns to **Driving Phase** and heads to its trip destination again. Here, tracking when a charging slot will be free is also as an input for computing EATC.

### C. CS-Selection Logic

If with a low battery electricity stage, an on-the-move EV (with its certain trip destination) has to firstly head to a selected CS (decided by the EV itself) for charging. If all charging slots of a CS are currently occupied (meaning all plug-in chargers are connected to other parking EVs), the incoming EV needs to wait until one of them is free. Upon departure from the CS, the EV will start to travel towards its trip destination again, with an initial maximum moving speed (e.g., speed acceleration).

The CS-selection logic is to find the CS, through which the EV will experience the shortest trip duration. Specifically:

- **Step 1:** Run at the CS side, it firstly checks the number of EVs currently being charged (meaning all charging slots are occupied). If there is a charging slot free for charging, the current time in network is returned, meaning that the CS is currently able to provide the charging service.
- **Step 2:** Run at the CS side, alternatively, it then checks the number of EVs waiting for charging (since there are EVs other than those being charged). Then the CS sorts the order of these EVs (waiting for charging) following the FCFS policy.
- **Step 3:** Run at the CS side, only concerning those EVs already being charged, the current EATC is found.
- **Step 4:** Run at the CS side, the current EATC is replaced with the charging finish time of a sorted EV (waiting for charging).
- **Step 5:** Steps 2-4 are repeated at the CS side, until the number of rest EVs waiting for charging reaches 0. Then an updated EATC is returned.

Either the output from Step 5 or Step 1 at each CS is published, aggregated and cached at PTBs, and is further accessed by EVs. The EV needs charging service then selects its preferred CS based on:

- Output from Step 1 or Step 5 (accessed from PTBs), in terms of the most recent EATC at a CS.
- Its arrival time and charging time at a CS. Note that if the EV arrival time is earlier than the updated EATC of a

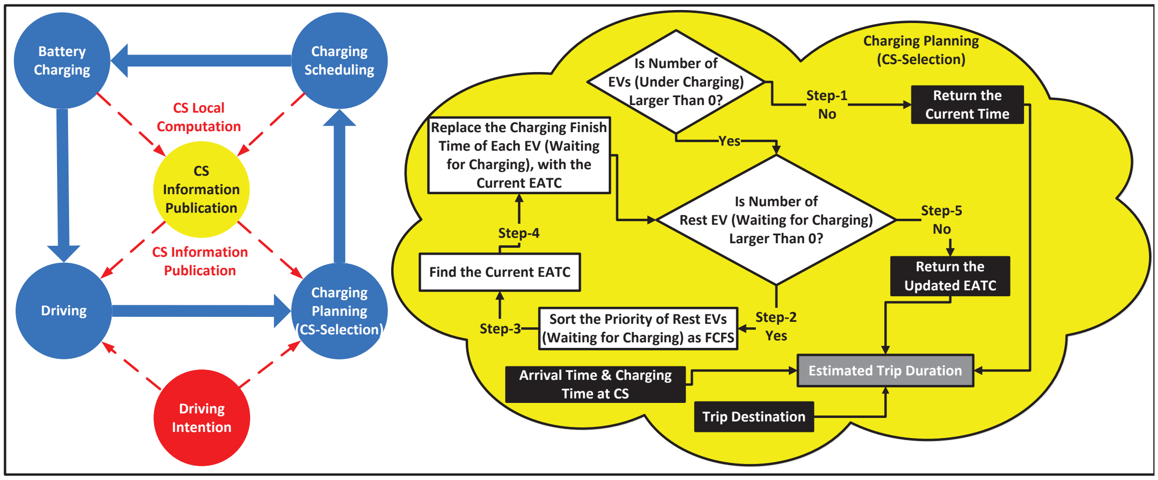



Fig. 3. System Cycle of On-the-move EV Charging Management

CS, this implies the EV still needs to wait for additional time for charging.

- Trip duration from that CS to its destination.

In summary, the shortest trip duration through an intermediate charging at a CS, is driven by the sum of time staying at that CS (including time to wait for charging and actual charging time), travelling time towards that CS, and travelling time from that CS to the EV's trip duration.

## V. Case Study

We have built up an entire system for EV charging in Opportunistic Network Environment (ONE) [11], a java based simulator originally used for DTN routing research. The underlying city scenario is based on the Helsinki in Finland with 8300×7400 m$^2$ area, containing four main districts A-D. Besides, there are three overlapping districts considering movements between the districts A and other districts, and one district covers the whole simulation area. In detail, district E includes A and B, F includes A and C, G includes A and D, and H covers from A to D. Every district is assigned its own bus route shown in Fig.4. Concerning the driving intention, we assign five types of Points Of Interests (POIs). The driving intention is influenced by the distribution of these POIs, where EVs will approach these POIs with a certain possibility.

300 EVs with $[2.7 \sim 13.9]$ $m/s$ variable moving speed are initialized considering road safety in a city. The configuration of EVs follows the charging specification {Maximum Electricity Capacity (MEC), Max Travelling Distance (MTD), Status Of Charge (SOC)}. Here, the electricity consumption for the Traveled Distance (TD) is calculated based on $\frac{\text{MEC}\times\text{TD}}{\text{MTD}}$. We configure the following EVs with 75 for each type:

- **Coda Automotive** [12] {33.8 kWh, 193 km, 30%}
- **Wheego Whip** [13] {30 kWh, 161 km, 40%}
- **Renault Fluence Z.E.** [14] {22 kWh, 160 km, 50%}
- **Hyundai BlueOn** [15] {16.4 kWh, 140 km, 60%}

Besides, 9 CSs are provided with sufficient electric energy and 3 charging slots through entire simulation, using the fast charging rate of 62 kW. The CS publication frequency is 300s by default. 5 PTBs with $[7 \sim 10]$ $m/s$ variable moving speed are eventually configured on each route. PTBs will stop for $[0 \sim 120]$s once a destination on their routes is reached. We consider a low power WiFi technique with a 100m transmission range, for EVs to communicate with PTBs.

For fair comparison, the on-the-move EV charging management (proposed in Section IV) based on **V-P/S** together with **V-OA**, **PB** and **CC** communication frameworks (discussed in Section III) are evaluated. The simulation time is 43200s = 12 hours.

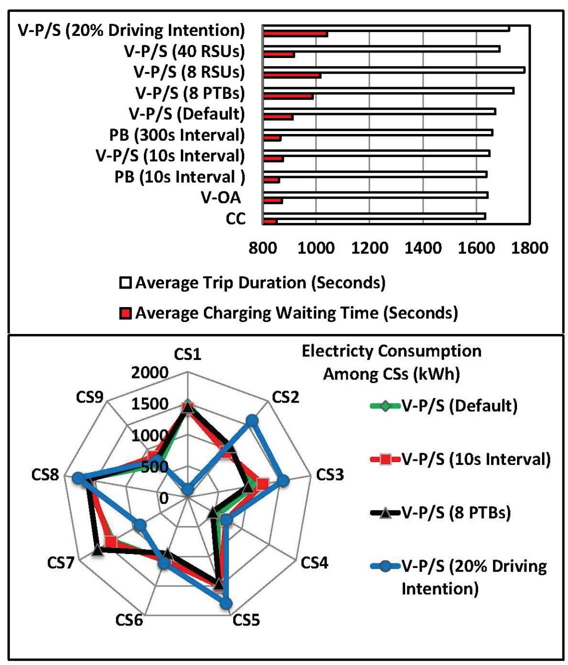



Fig. 5. Charging Performance

### *A. Influence of V-P/S Communication Framework Positioning*

The **Average Charging Waiting Time** reflects the average period between the time an EV arrives at the selected CS

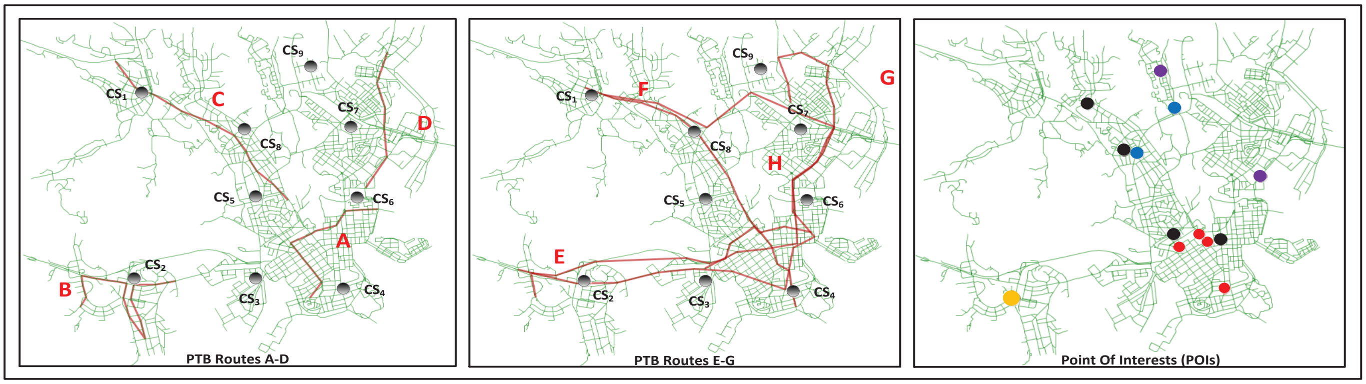



Fig. 4. Helsinki City Scenario (CSs Deployment + PTB Routes + Driving Intention)

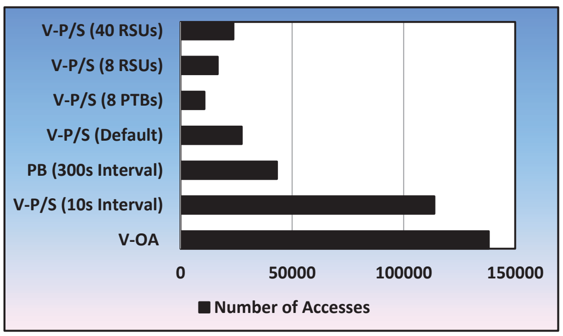



Fig. 6. Communication Side Performance

and the time it finishes recharging its battery. Besides, the **Average Trip Duration** reflects the average time that an EV experiences for its trip, through the recharging service at an intermediate CS.

In Fig.5, we observe that a frequent CS publication (meaning a short $T$ with 10s) leads to the best performance regarding charging waiting time and trip duration, which is close to that under the CC communication framework (Since the information is obtained accurately, its enabled charging performance is the best in terms of the shortest charging waiting time and trip duration). This reflects the efficiency of distributed charging management over centralized charging management, supported by the V-P/S communication framework. Besides, configuring a less number of PTBs (with 1 PTB per route, 8 PTBs in total) of course degrades this performance, due to less chances to access CSs condition information from a PTB. This leads to a realistic concern, by either setting more buses within a city, or enabling CSs to frequently publish their status information.

Turning to the performance at the CS side, we observe that an infrequent CS publication and a less number of PTBs lead to a fluctuation on the distribution of CSs' electricity consumption. In particular, if with 20% driving intention to each type of POI, the electricity consumption suffers from a substantial fluctuation.

### B. Benefit of V-P/S Communication Framework

In Fig.5, we observe that a frequent CS publication frequency (10s) is able for the PB, to achieve a close performance of that using the CC communication framework. Since the V-P/S (10s) relies on the opportunistic information dissemination from PTBs to EVs, its performance is slightly worse than that using the PB communication framework (with ubiquitous broadcasting nature). Interestingly, the V-P/S behaves closely to V-OA. This is due to that an accurate information is only needed, when EVs are making their CS-selection decisions. Whereas, setting 300s CS publication frequency degrades the charging performance, from which the importance of mobility-aware information dissemination is reflected, as the V-OA is comparable in this case.

We further deploy the same number of RSUs on each route instead of PTBs, results are quite interesting. On the one hand, deploying a less number of PTBs (with 1 PTB per route) outperforms that with 1 RSU per route (8 RSUs in total), regarding charging waiting time and trip duration in Fig.5. On the other hand, that performance in case of a high RSUs (with 8 RSUs per route, 40 RSUs in total) density, is close to that with 8 PTBs per route. This implies that if the coverage of relay entities is sufficiently large, the performance is towards saturation.

In this context, we claim the benefit of V-P/S for its flexibility (manageable depends on PTB routes) and low network configuration cost (requiring a less number of relay entities for information dissemination). Turning to the communication side performance, we observe that the V-P/S brings the least number of information accesses, than other options (V-OA suffers from redundancy due to accessing the same information from several buses). Note that the performance given PB (10s) is 1296000, which is substantially large and thus not included in Fig.6.

## VI. Discussions And Open Issues

### A. Oriented Information Dissemination

Practically, EV drivers would be only interested in charging services provided by CSs, within the range of their daily routines. Note the observation of drivers' routines requires a long-term analysis based on large scale historical data. It is reasonable to only disseminate certain CSs condition information that is associated with EV drivers' routines, through PTBs (with dedicated routes) running within that area.

### B. Advanced System Integration

Renewable energy (e.g., solar and wind) and advanced charging technologies (e.g., battery switch and wireless charging) can be integrated into the V-P/S system, through which the EATC publication requires further computation. Besides, the charging price and charging reservation could be integrated together with the EATC for publication, concerning the business model and anticipated status estimation of CSs. Further to these, PTBs (owned by different authorities) can bid with CSs (also owned by different service providers), to provide the advertisement of CSs condition information. This may depend on the working hours and PTB routes.

### C. Vehicle-to-Grid (V2G) Operation

Another area for collaboration is intelligently tying EVs into the power grid, so they can both take electricity from the grid as well as give it back. The V-P/S system can also support bidirectional information dissemination, where the information about when and which CSs that EV drivers will return their electricity, is bridged from EVs to CSs through PTBs.

## VII. Conclusion

In this article, we presented the V-P/S communication framework, for supporting on-the-move EV charging management. Results show the advantage of V-P/S over other alternative options, in terms of communication efficiency while with comparable charging performance regarding EV drivers' comfort. The open research issues have also been discussed.

## Acknowledgment

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