A Publish/Subscribe Communication Framework For Managing Electric Vehicle Charging

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***Abstract*—Electric Vehicle (EV) based applications have recently received wide interests from both commercial and research communities, thanks to the avoidance of CO_2 pollution by using electric energy instead of traditional fuel energy. With the deployment of public Charging Stations (CSs), the travelling distance of EVs could be substantially increased by recharging their electric energy during journeys. Different from the existing research on decision making to improve charging performance, in this paper we focus on how necessary dynamic information in relation to the charging service can be efficiently disseminated to on-the-move EVs which potentially require charging at CSs.**

We propose an efficient communication framework based on Publish/Subscribe (P/S) mechanism to disseminate necessary information of CSs to EVs. Those EVs subscribing to such information could then make their individual decisions to select a desired CS for charging, according to received information such as expected waiting time. A core part of communication framework is the utilization of Road Side Units (RSUs) to bridge the information flow from CSs to EVs, which has been regarded as a type of cost-efficient communication infrastructure. In this context, we introduce two complementary communication modes, namely Push and Pull Modes, in order to enable the required information dissemination operation. Both options are evaluated based on realistic simulation models, in particular on how information freshness can influence the overall charging performance based on a common CS selection strategy.

***Index Terms*—Smart Grid Communications, Electric Vehicle Charging, Publish/Subscribe, Information Freshness.**

I. Introduction

One of the distinct applications in smart grid is Electric Vehicles (EVs) [1], which enables complete avoidance of CO_2 emissions compared to traditional fuel based vehicles. It is anticipated that EVs will represent a sizeable portion of the US national transportation fleet, with around 50% of new electric car sales by 2050 [2]. However, adopting EVs will pose new challenges to the electricity grid, particularly in terms of EV charging management. In light of this, research on EV charging strategies for performance enhancement has received significant attentions from the research community.

In addition to the scenario considering home-based EV charging overnight, recent research works have also investigated the development of a public Charging Stations (CSs) in order to provide charging services during journeys. These public CSs are typically deployed at places where there is high concentration of EVs such as shopping mall parking places. In this case, on-the-move EVs requiring charging services have the opportunity to select the best CS for charging. On the other hand, due to the relatively long charging time for EVs, how to optimally schedule EV charging requests under uncertainty at the CS side has become a critical issue.

In order to achieve optimized charging performance such as minimizing waiting time at the EV side and also balanced load across multiple CSs, necessary information about the CS conditions can be disseminated to EVs as input for making their charging decisions. Based on a given EV's strategy to select the dedicated CS for charging such as minimum waiting time [3], the information freshness for dynamic CS status from a CS to EVs plays an important role on the actual charging performance. For instance, if the received information about the estimated waiting time at each CS is substantially outdated, then the EVs using such obsolete information might make inappropriate decisions through On-Board Unit (OBU). Under both scenarios, the unbalanced EV charging request at CSs will result in suboptimal electric energy demand load among them, and also unexpected longer waiting time at the EV side. As such, how frequent such information is distributed to EVs may have a significant impact on the final EV charging performance.

As far as the communication infrastructures are concerned, having been widely applied in Vehicular Ad hoc NETworks (VANETs), the Publish/Subscribe (P/S) [4] is considered as a suitable communication paradigm for building applications with highly dynamic, flexible nature. Focusing on the EV charging application, the P/S can be applied as a solution scheme, in which each CS as a publisher publishes its own status information (such as estimated waiting time, location, price etc.) to the EVs as subscribers of the information. By referring to Road Side Units (RSUs) in VANETs to enable Vehicle to Infrastructure (V2I) communications, strategically deployed RSUs at given fixed locations can be used for information dissemination as the support for EV charging scheduling operations [5]. Practically, there are multiple communication technologies that can be used for realizing RSU functions, such as cellular networks and WiFi access points. While the cellular technology ensures much wider radio coverage, it is generally deemed as an expensive solution compared to WiFi [6]. Indeed, for information dissemination in the EV charging scenario, it is not always necessary to have ubiquitous radio coverage for on-the-move EVs, but it can be easily inferred that the RSU radio coverage will have an impact on the information freshness for EV charging application.

In this paper, we present an efficient P/S communication framework for disseminating the status information of CSs, in order to achieve optimized EV charging performances. Two communication modes are introduced, namely Push Mode and Pull Mode:

- Under the Push Mode, CSs periodically publish their condition information to nearby RSUs, from which the data is directly disseminated to the on-the-move EVs within the radio coverage of those RSUs.
- Under the Pull Mode, the CS condition information is periodically published to the RSUs with data storage space and gets cached there. When an EV enters the radio coverage of a RSU which holds the message, it can query through that RSU in order to fetch the latest cached information.

It can be inferred that, if the radio coverage is not ubiquitous (e.g., the WiFi scenario in which the communication is disruptive), an EV may miss the published information while it traverses the radio coverage of that RSU (depending on the CS publication frequency), thus affecting the received information freshness. As such, the other objective of the paper is to analyze the RSU deployment strategies, which is also linked to the control of CS information publication frequency for enabling optimized EV charging performances on both the CS and the EV sides. In addition, the proposed schemes can be used for advertising price information. However, since the charging price normally does not vary significantly across CSs and also it's not changed very dynamically, we mainly focus on the waiting time issue in this paper.

The rest of the paper is organized as follows. In section II we present the related work, followed by section III in which we introduce the overall system design. In this section we specify detailed design of the two P/S based communication modes for enabling V2I communications in order to support EV charging management, namely the Push Mode and the Pull Mode. Then we present an analytical model to evaluate the efficiency of the two modes based on a common-practice decision making logic for CS selection. In section IV we present comprehensive simulation results based on a realistic simulation scenario for evaluating information freshness achieved by publication frequency, and how it actually impacts the charging performance at both the EV side and the CS side.

II. Related Work

On one hand, most of previous works target at saving charging cost, by minimizing peak loads to flatten aggregated demands. For instance, two decentralized control strategies [7], [8] are proposed for EV charging, by establishing a charging schedule that fills the overnight demand valley. In [9], a prediction-based charging scheme is presented to achieve low charging cost by dynamically predicting the market prices during the charging period and determining the appropriate time to charge. On the other hand, only few works have addressed the problem of designing selection and scheduling schemes to alleviate the user's discomfort, by minimizing the waiting time for EV charging at CS. The work in [3] relies on a global control center connected to all CSs, such that EVs requiring for charging will send request to obtain the status information of CSs. The work in [10] presents an advanced Information and Communication Technology (ICT) infrastructure to minimize the EV charging time, based on a distributed infrastructure including local controller and global controller. Specifically, this work compares the schemes to select CS based on the closest distance and minimum waiting time, where results show that the latter performs better given high density of EVs for charging. Besides, in [11], CSs are considered to relay the information such as waiting time or EV reservation for charging scheduling, where the route information has been taken into account for performance optimization as well.

It is highlighted that none of previous works has adopted the P/S mechanism to disseminate infrastructure information for EV charging application. Here, we utilize RSU to bridge the information from CS to EV, rather than relying on the direct communication between CS and EV via cellular network connection. Different from classical communication mechanism using address to identify receiver, the P/S mechanism allows event distribution from publisher (event producer) to subscriber (event consumer) without the use of any explicit address. Here, the event distribution is based on declared subscribers' interests. This mechanism mainly offers communications decoupled in space that subscribers do not need to know publishers and vice-versa), and potentially in time if the system is able to store events for clients which are temporally disconnected (such as the intermittent connection resulting from highly network dynamic and sparse network density in Delay/Disruption Tolerant Networks (DTNs) [12]).

III. System Design

A. Overview

In this paper, the EV, CS and RSU are three major entities in our scenario:

Electric Vehicle (EV): Each 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 would select an appropriate CS, then travel to that given CS for charging.

Charging Station (CS): Each CS is deployed at a certain location, while it periodically publishes its status information such as waiting time, such that the EV requesting for charging could utilize this information for selecting CS.

Road Side Unit (RSU): The deployed RSU behaves as an intermediate entity for bridging the information flow from each CS to those EVs passing through RSU.

B. Two Communication Modes

Under the Push Mode as shown in Fig.1, the EV, as the subscriber, passively receives information from a nearby RSU. This happens when the EV is within the radio coverage of that RSU, as given by $D \leq R$. Here, D is the distance between RSU and EV, while R is the radius of RSU radio coverage. Note that the RSU under this mode will not cache any historical information received from CS, thus a communicating

EV can not obtain any information if CSs are not currently publishing their information.

Under the Pull Mode, each RSU locally caches the information from a CS as the historical record. The EV with L radius coverage initially sends an explicit query to the RSU, when their current distance is smaller than the minimum value between their radio coverage, as given by $D \leq \min[R, L]$. In general, we consider $L < R$. Upon receiving this query, the RSU then sends its latest cached information to that EV, as shown in Fig.2. Note that once a new value has been received, it will replace the obsolete values in the past, that are not necessarily maintained by RSUs. Different from passively receiving information for multiple times from each RSU under the Push Mode, here, each EV can only obtain the information from each RSU only once.

C. Analysis

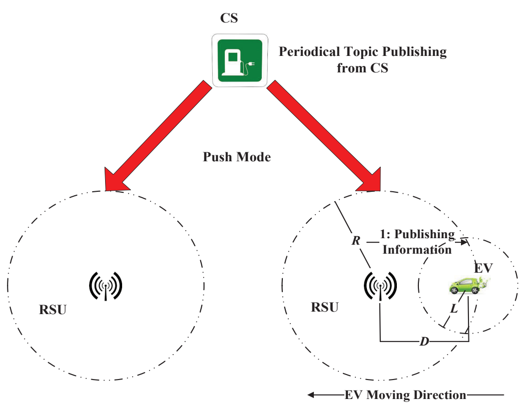


Fig. 1. Push Mode

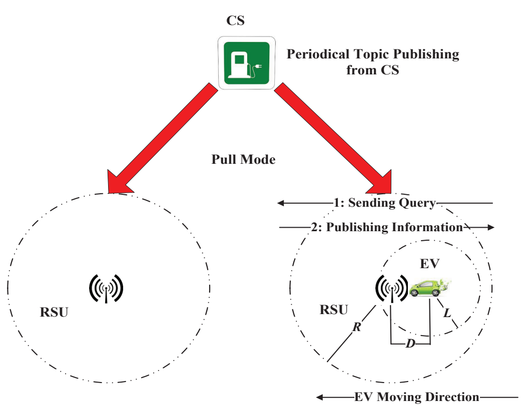


Fig. 2. Pull Mode

We assume all EVs could obtain the location of each CS directly via the navigation system, and this CS has sufficient electric energy for charging all the time. Our communication framework is based on the situation that each CS periodically publishes information in relation to its waiting time, based on a sum of charging time estimated for EVs parking at this CS. In general, each EV will leave from CS once its energy is fully charged. The CS is connected to all RSUs on the straight road for simplicity, while there is no overlap between the radio coverage of two adjacent RSUs, for instance in the WiFi scenario where the radio coverage is not ubiquitous. For the purpose of analysis, we model an event, that an EV leaving from a RSU and moving to next one, based on a constant moving speed moving on a straight road.

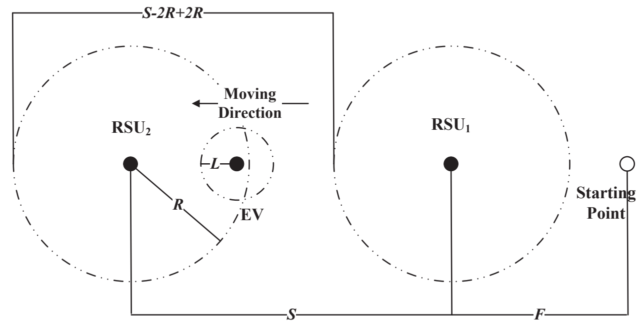


Fig. 3. Analysis Scenario

1) Push Mode: First, the probability P_1 that an EV is within the radius range of RSU is $\frac{2R}{S-2R+2R} = \frac{2R}{S}$, where $P_1 \leq 1$ indicates the radio coverage of two adjacent RSUs is not overlapping. Note that $2R$ is the distance an EV passing through a RSU, while $S - 2R$ is the radius gap between 2 adjacent RSUs. In this context, $S - 2R + 2R$ is the distance from the edge of one RSU to the edge of next RSU.

Considering the constant speed V of an EV, $\frac{2R}{V}$ is calculated as the time passing through that RSU. Then the ratio between this value and the updating interval T stands for the probability P_2, that an EV can receive the information from a newly communicating RSU, calculated as $\frac{2R/V}{T} = \frac{2R}{V \cdot T}$.

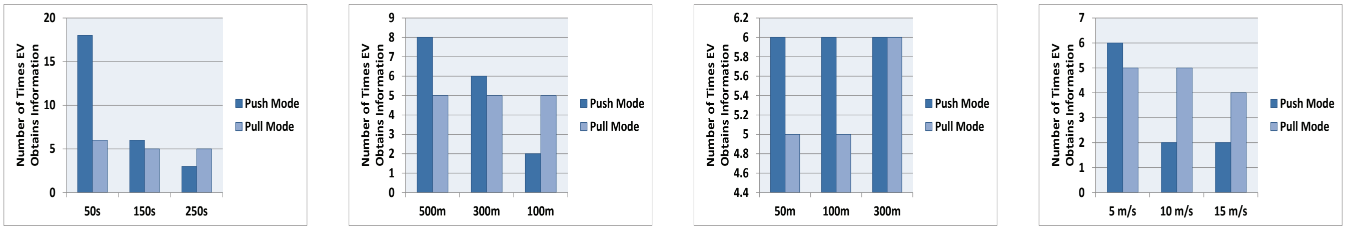
Since P_1 and P_2 are independent events, the probability P_{ob}, that an EV can obtain information from a newly communicating RSU, given that it leaves from a previous RSU to the edge of current one, is calculated as $P_1 \cdot P_2 = \frac{4R^2}{V \cdot T \cdot S}$. Note that this joint probability is uniform for an EV passing through any two adjacent RSUs, under the Push Mode only.

Concerning the probability P_f that when the EV just passing through the first RSU, $\frac{(F-R)/V}{T} \leq P_f \leq \frac{(F+R)/V}{T}$ includes the lower bound and upper bound of the probability, considering that the EV entering and leaving from the radio coverage of the first RSU. Here, F is the distance measured from the starting point to the first RSU on the road. For generalization, we choose the upper bound value.

Considering there are N RSUs with equal adjacent distance S on a straight road, the probability P_{push} that an EV can get information from at least one RSU is calculated as:

$$\begin{aligned} P_{push} &= 1 - (1 - P_f)(1 - P_{ob})^{(N-1)} \\ &\leq 1 - \left(1 - \frac{F+R}{V \cdot T}\right)\left(1 - \frac{4R^2}{V \cdot T \cdot S}\right)^{(N-1)} \end{aligned} \tag{1}$$

We observe that the possibility that an EV getting information relies on a larger radio coverage and number of RSUs in



(a) Influence of T (b) Influence of R (c) Influence of L (d) Influence of V

Fig. 4. Influence of T, R, L and V Under Straight Road Scenario

general. Meanwhile, a more frequent update interval and slower EV moving speed also improve such probability. Recall we consider that there is no overlap between the radio coverage of two adjacent RSUs, thus a closer distance between them is beneficial to increase P_{push} as well.

2) Pull Mode: Here, since the EV has to send query to the RSU for requesting the information, the radio coverage of EV needs to be taken into account. Different from that under the Push Mode, the probability that an EV obtains information is gradually increased when passing through more RSUs, due to the caching nature of RSUs. In this case, this given probability depends on whether the RSU has the historical record about the CS when communicating with the EV. Inherently, a longer elapsed travelling time indicates a higher probability, as the RSU has more chance to cache the historical information of CS.

The analysis is decoupled as follows:

- When the EV communicating with the first RSU, $\frac{(F-L)/V}{T} \leq P_f \leq \frac{(F+L)/V}{T}$ includes the lower bound and upper bound of the probability, considering cases when the connection between EV and RSU is established and disrupted.
- Upon leaving from the first RSU and communicating with second RSU, P_{ob} is calculated by $\frac{(S+F-L)/V}{T} \leq P_{ob} \leq \frac{(S+F+L)/V}{T}$.
- By generalizing the above two steps, when the EV is communicating with the i^{th} RSU, the target value is increased by $\frac{[(i-1)S+F-L]/V}{T} \leq P_{ob} \leq \frac{[(i-1)S+F+L]/V}{T}$.

Here, we also choose the upper bound for generalization, that:

$$\begin{aligned} P_{pull} &= 1-(1-P_f)(1-P_{ob})^{(N-1)} \\ &\leq 1-\left(1-\frac{F+L}{V\cdot T}\right)\prod_{i=2}^{N-1}\left\{1-\left[\frac{(i-1)S+F+L}{V\cdot T}\right]\right\} \\ &= 1-\prod_{i=1}^{N}\left\{1-\left[\frac{(i-1)S+F+L}{V\cdot T}\right]\right\} \end{aligned} \tag{2}$$

It is observed that increasing the radio coverage of EV improves this given probability to obtain information from RSUs. Similar to that under the Push Mode, the influence of V and T are also applicable in this case. However, since it is beneficial to wait for a longer time to cache the historical information of CS under the Pull Mode, a larger S is desirable.

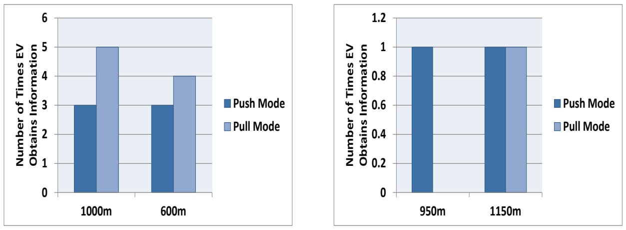
3) Simulation Validation: In order to validate the influence of above factors, we adopt a simple scenario as a straight road with 6000m length. Here, 6 RSUs are deployed starting from the 500m point on the road, with uniform 1000m distance gap between any adjacent RSUs. The radio coverage of RSU is fixed as 300m, such that there is no overlap between adjacent RSUs. We mainly simulate the event that how many times that an EV could receive information from RSU when passing through this road. The default radio coverage range of EV is fixed as 100m while its constant moving speed is fixed as 5m/s. The update interval of CS is 150s by default.

Concerning communication pattern, when increasing the update interval T in Fig.4(a), the capability of obtaining information under the Push Mode is dramatically decreased compared to that under the Pull Mode. Given a smaller radio coverage of RSU in Fig.4(b), we observe that the performance under the Push Mode is thereby degraded, following our analysis. Since the Pull Mode considers the minimum radio coverage between RSU and EV, it maintains performance in this case. Besides, the performance under the Pull Mode is improved by increasing the radio coverage of EV in Fig.4(c), as the EV has a longer communication duration to await RSUs to cache information from CS.

Concerning mobility pattern, we increase the moving speed of EV in Fig.4(d), where the Push Mode suffers more from this variation, due to the fact that the EV passing through RSUs without caching the historical information may have a less chance to obtain information from them.

Finally, we concern the factors of deployment. In Fig.5(a) based on 250s update interval, a closer distance between adjacent RSUs degrades the capability of EV to obtain information. Note that since 3 times is the default performance given 250s update interval, the EV under the Push Mode could not obtain performance improvement. We next deploy only one RSU to show the influence of F. In Fig.5(b) where only the first RSU is deployed and 250s update interval is applied by CS, the result shows that in order to obtain the information from this RSU, the communication framework under the Pull Mode requires a longer starting distance F, in contrast to that under the Push Mode.

4) Comparison Between Push And Pull Modes: Recall that the radio coverage between two adjacent RSUs is not ubiquitous, thus we have $2R \leq S$. Then the upper bound of



(a) Influence of S (b) Influence of F

Fig. 5. Influence of S and F Under Straight Road Scenario

P_{push} can be converted as:

$$\begin{aligned} P_{push}^{upper} &= 1 - \left(1 - \frac{F+R}{V \cdot T}\right)\left(1 - \frac{4R^2}{V \cdot T \cdot S}\right)^{(N-1)} \\ &\leq 1 - \left(1 - \frac{F+R}{V \cdot T}\right)\left(1 - \frac{S^2}{V \cdot T \cdot S}\right)^{(N-1)} \\ &= 1 - \left(1 - \frac{F+R}{V \cdot T}\right)\left(1 - \frac{S}{V \cdot T}\right)^{(N-1)} \end{aligned} \tag{3}$$

Next, the upper bound of P_{pull} can be converted as:

$$\begin{aligned} P_{pull}^{upper} &= 1 - \prod_{i=1}^{N} \left\{1 - \left[\frac{(i-1)S + F + L}{V \cdot T}\right]\right\} \\ &> 1 - \left(1 - \frac{F+L}{V \cdot T}\right) \prod_{i=2}^{N} \left\{1 - \left[\frac{(2-1)S + F + L}{V \cdot T}\right]\right\} \\ &= 1 - \left(1 - \frac{F+L}{V \cdot T}\right)\left(1 - \frac{S+F+L}{V \cdot T}\right)^{(N-1)} \end{aligned} \tag{4}$$

Based on the above, it is observed that if configuring $R = L$ for fairness, the Pull Mode always achieves a higher probability to obtain information from RSUs than Push Mode.

It is worth noting that although our analysis herein is based on the ideal case where EVs are moving on a straight road with constant speed, our following evaluation results show that such analysis is also applicable to a city scenario where the road topology is complicated and EVs move with varied speed.

D. Decision Making Procedure for EV Charging

All CSs are connected with each RSU through dedicated and reliable communication channels. While each EV communicates with RSUs to gather status information about all CSs.

The EV reaching a threshold on its residual battery charge applies a pre-defined policy to select a dedicated CS for charging, using the information obtained from RSU. Note this EV might have received information for several times when it is reaching the threshold for requesting charging. Here, each EV selects a dedicated CS within the EV's reachability, based on the minimum waiting time. Since EVs' decision making is always based on the latest published information, the information freshness (which affects the actual charging performance) effectively depends on how often the periodically published information is received by the on-the-move EVs. In the worst case, the EV would select a CS with the shortest geographic distance as a back-up scheme, if none of the information in relation to any CS is obtained from RSUs. Note that this situation typically happens when that EV misses all update when traversing RSUs' radio coverage. Finally, upon reaching the selected CS, EVs are then scheduled based on the First Come First Serve (FCFS) priority for charging.

TABLE I
LIST OF NOTATIONS

N_C	Number of EVs under charging at CS
N_W	Number of EVs waiting for charging at CS
ϑ	Number of charging slots at CS
E_{ev}^{max}	Full volume of EV battery
E_{ev}^{cur}	Current volume of EV battery
β	Charging power at CS

The waiting time at CS is computed as the sum of the charging time, for each EV currently parking at this CS. In order to calculate this information, we need the following information:

- Number of EVs under charging, denoted by N_C.
- Local charging time of each EV parking at CS, as given by $\frac{E_{ev}^{max} - E_{ev}^{cur}}{\beta}$.
- Number of charging slots at CS, denoted by ϑ.
- Number of parked EVs which are still waiting for available charging slots, denoted by N_W.

Algorithm 1 GettingMinimumChargingTime

define $min = +\infty$
for $i = 1; i \leq N_C; i++$ **do**
  if $\frac{E_{ev(i)}^{max} - E_{ev(i)}^{cur}}{\beta} < min$ **then**
    $min = \frac{E_{ev(i)}^{max} - E_{ev(i)}^{cur}}{\beta}$
  end if
end for
return min

The calculation of waiting time, or referred to the local queuing time at CS is decoupled as follows: Firstly, since the number of EVs under charging can not exceed the value of ϑ, the remaining time to wait for an available charging slot is equivalent to the minimum charging time of those EVs being charged, if all charging slots are occupied as presented in Algorithm 1. Secondly, another factor from those N_W number of EVs still waiting for charging is to calculate an accumulative value of their charging time, presented between lines 8 and 9 in Algorithm 2. In special case as presented between lines 3 and 6, one of the parked EVs will be scheduled for charging given $N_C < \vartheta$, indicating that there is at least one available charging slot. For each update interval, CS will calculate its waiting time and publish this information to RSUs.

IV. PERFORMANCE EVALUATION

A. Scenario Configuration

We have built up an entire system for EV charging in Opportunistic Network Environment (ONE) [13], a java based simulator particularly developed for research in DTNs. In Fig.6, the default scenario with 4500×3400 m^2 area is shown

Algorithm 2 CalculatingLocalQueuingTime

define $value_1 = 0$
define $value_2 = 0$
if $N_C < \vartheta$ **then**
  schedule an EV for charging based on FCFS
  $N_C = N_C + 1$
  $N_W = N_W - 1$
end if
for $i = 1$; $i \leq N_W$; $i++$ **do**
  $value_1 = value_1 + \frac{E_{ev(i)}^{max} - E_{ev(i)}^{cur}}{\beta}$
end for
$value_2 =$ GettingMinimumChargingTime
return $value_1 + value_2$

Fig. 6. Simulation Scenario of Helsinki City

as the down town area of Helsinki city in Finland. Here, 100 EVs with $[5 \sim 10]$ m/s variable moving speed are initialized in the network. The configuration of EVs follows the charging specification (Maximum Electricity Capacity (MEC), Max Travelling Distance (MTD): 30 kWh, 161 km) of Wheego Whip EV [14]. Here, the electricity consumption for the Traveled Distance (TD) is calculated based on $\frac{\text{MEC} \times \text{TD}}{\text{MTD}}$, and we set SOC $= 60\%$ for EV to start selecting CS. Here, the shortest path towards CS is formed considering road topology.

For simplicity, 5 CSs are provided with 3000 KWh electric energy and 3 charging slots through entire 12 hours' simulation, using the fast charging rate of 62 kW. For the purpose of fairness, 300m radio coverage is applied for 7 RSUs and 100 EVs, as we aim to examine the performance under the Push Mode and Pull Mode given same condition. The default CS update interval is 100s.

B. Comparable Performance Metrics

We also evaluate the charging system based on the ideal case, that each EV could obtain the realtime waiting time by sending request and receiving reply from a global controller. We mainly concern the performance in relation to communication patterns, with 95% confidence interval based on 10 runs. The evaluation metrics are as follows:

- **Average Waiting Time**: The average period of time between the time an EV arrives to the selected CS and the time it finishes recharging its battery.
- **Number of Times EVs Obtain information**: The total number of times that all EVs obtain information from RSUs.
- **Average Information Freshness**: The average value of the difference between the current waiting time at CS side and that recorded at EV side, only calculated when an EV makes an individual selection decision.
- **Utilization of CSs**: The amount of consumed electric energy calculated at CS side.
- **Number of Charged EVs**: The total number of fully charged EVs in the network.

C. Influence of Update Interval

In Fig.7(a), with an infrequent update interval of CS, all EVs in the network experience an increased average waiting time. This is due to the fact that using an outdated information affects the computation at the EV side to make selection decision. In other words, the number of EVs waiting at CS, as estimated at the EV side when making decision, may be significantly different from that at the CS side. Thus, with an increased update interval, there will be a huge difference between that performance given 100s and 900s interval. In particular, by relying on the realtime information of CSs in Ideal Case, the obtained information is the same as the status of CSs. As such, the performance under the Ideal Case achieves the lowest average waiting time in Fig.7(a), particularly when both Push and Pull Modes are based on 900s update interval.

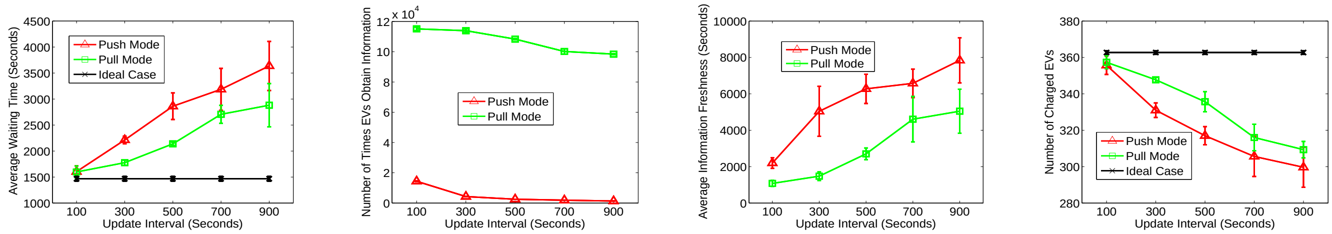
In Fig.7(b), the number of times EVs obtain information is decreased given a longer update interval, where this performance under the Push Mode is worse than that under the Pull Mode. Upon this result, we observe the decreased number of times to obtain information results in poor information freshness in Fig.7(c). Therefore, all EVs will experience a longer waiting time due to using outdated information for selecting a CS, which results in a lower number of charged EVs in Fig.7(d).

Comparing with the results in Fig.8(a) and Fig.8(b), we further observe that the number of times to obtain information has influence on the utilization of CSs. This is because that the poor information freshness yields EVs to make inaccurate selection decision, as such the electric energy at some CSs may not be utilized for charging. The above observation becomes more significantly given 900s update interval.

D. Summary of Results

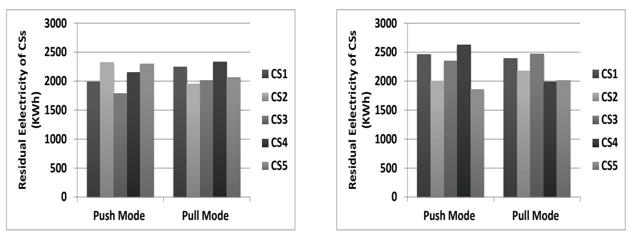
With the above results in mind, we have the following observations when concerning the communication pattern:

- The number of times EVs obtain information affects the quality of information for making decision, where a reduced chance to obtain information thereby results in worse information freshness.



(a) Average Waiting Time (b) Number of Times EVs Obtain Information (c) Average Information Freshness (d) Number of Charged EVs

Fig. 7. Influence of Update Interval T



(a) 100s Update Interval (b) 900s Update Interval

Fig. 8. Utilization of CSs

- A worse information freshness results in an increased average waiting time, as EVs using relatively outdated information for selecting CS would yield unbalanced charging demand among all CSs in the network.
- Due to a longer average waiting time at CS for charging, the number of charged EVs is reduced within the given simulation period, and therefore the CS utilization is reduced.
- The main advantage of using the Pull Mode, as the communication framework on top of charging system, is the flexibility and higher utilization of CSs given sparsely deployed RSUs.

V. Conclusion

In this paper, we proposed an efficient communication framework for EV application, based on the P/S mechanism and deployed RSUs to disseminate the status information of CSs. Here, two communication modes are specified. The Push Mode only allows RSUs to bridge the current status information from CSs to EVs. In contrast, the Pull Mode allows RSUs to cache the historical record of such information, which potentially improves the probability that EVs obtain information from RSUs. We analyzed this probability under two communication modes, depending on factors in relation to communication, mobility as well as deployment patterns. Upon this analysis, we further developed the entire charging decision making system via ONE simulator, as for a typical EV scenario. Concerning the communication pattern, evaluation results showed that the a decreased number of times EVs obtain information from RSUs deteriorates the performance regarding average waiting time as well as information freshness, concerning the EV perspective. Meanwhile, at CS side, the number of charged EVs as well as utilization of electric energy are also reduced.

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