

# Northumbria Research Link

Citation: Cao, Yue, Kaiwartya, Omprakash, Zhuang, Yuan, Ahmad, Naveed, Sun, Yan and Lloret, Jaime (2019) A Decentralized Deadline-Driven Electric Vehicle Charging Recommendation. IEEE Systems Journal, 13 (3). pp. 3410-3421. ISSN 1932-8184

Published by: IEEE

URL: <https://doi.org/10.1109/JSYST.2018.2851140>  
<<https://doi.org/10.1109/JSYST.2018.2851140>>

This version was downloaded from Northumbria Research Link:  
<http://nrl.northumbria.ac.uk/id/eprint/35748/>

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: <http://nrl.northumbria.ac.uk/policies.html>

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)



**Northumbria  
University**  
NEWCASTLE



**UniversityLibrary**

# A Decentralized Deadline Driven Electric Vehicle Charging Recommendation

Yue Cao, *Member, IEEE*, Omprakash Kaiwartya, *Member, IEEE*, Yuan Zhuang, *Member, IEEE*, Naveed Ahmad, Yan Sun and Jaime Lloret, *Senior Member, IEEE*

**Abstract**—The Electric Vehicle (EV) industry has been rapidly developing internationally due to a confluence of factors such as government support, industry shifts, and private consumer demand. Envisioning for the future connected vehicles, the popularity of EVs will have to handle massive information exchange for charging demand. That inevitably brings much concern on network traffic overhead, information processing and security etc. Data analytics could enable the move from Internet of EVs, to optimized EV charging in smart transportation. In this paper, a Mobile Edge Computing (MEC) supporting architecture along with intelligent EV charging recommendation strategy is designed. The Global Controller (GC) behaves as centralized cloud server to facilitate analytics from CSs (service providers) and charging reservation of on-the-move EVs (mobile clients), to predict the charging availability of CSs. Besides, Road Side Units (RSUs) behave as MEC servers to help with dissemination of CSs' charging availability to EVs, and collecting their charging reservations, as well as operating decentralized computing on reservations mining and aggregation. Evaluation results show the feature of MEC based charging recommendation system in terms of communication efficiency (low cost for information dissemination and collection), and improvement of charging performance (reduced charging waiting time and increased fully charged EVs).

**Index Terms**—Electric Vehicle, Charging Recommendation, Mobile Edge Computing, Vehicle-to-Infrastructure.

## I. INTRODUCTION

**T**HE introduction of Electric Vehicles (EVs) [?] will have a significant impact on the sustainable economic development of urban city. Whereas, even if there have been charging service providers available, the utilization of charging infrastructures is still in need of significant enhancement. Such a situation certainly requires the popularity of EVs towards the sustainable, green and economic market. Enabling the sustainability requires a joint contribution from each domain, e.g., how to schedule charging services for EVs being parked within grid capacity, how to optimally recommend EV drivers towards Charging Station (CS) with the least waiting time,

how to guarantee accurate information involved in decision making.

Unlike many previous works [?] which investigate “charging scheduling” (referred to when/whether to charge) for EVs already been parked at CSs, recently a few works focus on “charging recommendation” (refer to where/which CS to charge) [?] for on-the-move EVs. The latter case has been the most important feature of improving the charging Quality of Experience (QoE), as applied by operators. Thus it is important to optimally recommend EV drivers regarding where to charge, concerning the service waiting time.

Literature works [?], [?], [?], [?], [?] have addressed charging recommendation to improve the charging QoE (e.g., to reduce the service waiting time for charging). Usually, the local condition of CSs (e.g., number of EVs being parked and their remaining charging time) [?] is considered to make charging recommendation decision. Further advanced solutions utilize the EV's charging reservation [?], [?], [?], [?] to align with the local condition of CSs. By doing so, at what time and which CS will be congested can be predicted, so as not to be recommended for charging. Here, the charging reservation includes arrival time (when an EV will arrive at recommended CS) and expected charging time at the selected CS (how long its charging time will be).

Practically, EV drivers would also have their parking deadline [?] at CSs (e.g., drivers might be impatient to wait for long time, or have another daily agent after certain period of charging). Particularly, in case of charging during peak time, already deployed charging slots at CSs may not be sufficient to handle such a urgent charging demand (due to limited parking duration). Inevitably, inappropriate charging recommendation would degrade charging QoE, as some EVs will have to leave after the deadline whereas not yet been charged. Consequently, additional effort and energy consumption will be taken for charging, such inconvenience would however degrade the willingness to switch from traditional vehicles to EVs.

The centralized cloud based system [?] is widely applied in literature for charging recommendation. Such system generally relies on ubiquitous cellular network and real-time information for optimization. For example, previous work [?] adopted a cloud-based Global Controller (GC) connecting to all CSs. Whenever an EV requires for charging, it will send a request to the GC through cellular network for seeking the best CS recommendation, and further reports its charging reservation. By facilitating the anticipated EV charging recommendation, the charging availability of CS can be predicted, such that the cloud will not recommend a CS with low availability.

Y.Cao is with the Department of Computer and Information Sciences, Northumbria University, UK. Email: yue.cao@northumbria.ac.uk

O.Kaiwartya is with the School of Science and Technology, Nottingham Trent University, UK. Email: omprakash.kaiwartya@ntu.ac.uk

Y.Zhuang is with Bluvision Inc., Part of HID Global, US. Email: zhy.0908@gmail.com

N.Ahmad is with the Department of Computer Science, University of Peshawar, Pakistan. Email: n.ahmad@upesh.edu.pk

Y.Sun is with the School of Electronic Engineering and Computer Science, Queen Mary University of London, UK. Email: yan.sun@qmul.ac.uk

J. Lloret is with the Universitat Politècnica de Valencia, Valencia, Spain, Email: jlloret@dcom.upv.es

However, by seamlessly collecting information from EVs and CSs, it is very time-consuming for the GC to achieve optimization. The complexity and computation load of cloud server, increases exponentially (depends on those are currently request charging and those have made charging reservations) with the number of EVs. Moreover, the cellular network is costly and sometime over-congested due to massive accesses, which degrades the communication quality. The rapid growth of mobile applications have placed severe demands on cloud infrastructure, which has led to moving computing and data services towards the edge of the cloud, resulting in a novel Mobile Edge Computing (MEC) [?] (also known as fog computing) architecture being developed by the European Telecommunications Standards Institute (ETSI) and creating a new Industry Specification Group in 2014 for this purpose. MEC could reduce data transfer times, remove potential performance bottlenecks, and increase data security and enhance privacy while enabling advanced applications.

As such, for EV charging use case, decentralized charging recommendation with the assistance of MEC servers positioned close to EVs is desirable. Apart from cellular network, a cheaper solution nowadays is the deployment of fixed Road Side Units (RSUs) [?] based on licence-free spectrum such as WiFi, but only with limited network coverage. Future Intelligent Transportation Systems (ITS) [?] will necessitate infrastructure assisted communication for EV charging perspective in addition to road safety perspective. In [?], a decentralized MEC based ICT framework has been proposed where it facilitates the RSUs (with MEC servers) to perform information caching, aggregation and lightweight processing (e.g., access control and information mining), system level communication cost within the charging recommendation system can be reduced. Besides, by cooperating with the cloud server GC, deployed RSUs also help to disseminate and collect information between CSs and EVs ubiquitously.

Understandably, the integration of ICT, transport and energy is important for the attainability of EV charging [?], [?]. This paper mainly tackles a joint study of former transport planning and ICT, whereas the integration of energy sustainability (e.g., smart charging, scheduling of renewable energy) is out of the scope. Beyond ICT effort investigated in [?], we further take the impact of parking deadline and that decentralized ICT framework into account for EV charging recommendation decision. More specifically, the EV's parking deadline will influence the estimation of CSs' charging queueing, and prediction of their charging availability (in line with EVs' charging reservations collected through the positioned MEC architecture). In particular, the proposed solution on predicting charging availability is decoupled and associated with a number of time intervals (within a dynamically updated time window). Such a feature benefits to the accuracy of charging recommendation, bounded by a prediction time window and EV mobility.

## II. RELATED WORK

### A. Cloud/Mobile Edge Computing in Smart Transportation

Smart transportation can fundamentally change urban lives at many levels. Data from service providers and users bridged

via an ubiquitous, dynamic, scalable, sustainable ecosystem, would offer a wide range of benefits and opportunities. Most of the existing techniques require high processing time using conventional methods of data processing [?]. Therefore, techniques are desirable to efficiently process the data generated from stakeholders, ideally from distributed manner through ubiquitously disseminated and collected information.

The major difference between cloud computing [?] and MEC [?], is on the location awareness to support application services. This is because the cloud server locates in a centralized place, behaves as a centralized manager to perform computation tasks. Note that, MEC servers at different locations can be 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.

### B. EV Charging Recommendation

As reviewed by the most recent survey [?], fruitful literature works have addressed "charging scheduling" [?], via regulating the EV charging, such as minimizing peak load/cost, flattening aggregated demands or reducing frequency fluctuations.

In recent few years, the "charging recommendation" problem has started to gain interest from industrial thanks to the popularity of EVs. The generic solutions [?], [?] make decision based on the queueing information at CSs, and the one with the minimum queueing time is recommended. This feature has been evaluated in [?] against with the charging recommendation just taking the closest distance to CS, the former is deemed as an effective guidance in urban city with limited charging infrastructures.

The charging recommendation solution in [?] adopts a pricing strategy to minimize congestion and maximize profit, by adapting the price depending on the number of EVs charging.

Beyond that, the integration of ICT and energy network is of importance for the sustainability of EV charging, where a set of works have addressed the constraint of energy network and study its impact. From ICT aspect, additional communication signalling is built to support the advanced charging recommendation brings anticipated EVs mobility information (charging reservations). The work in [?] concerns a highway scenario where the EV will pass through all CSs. The expected charging waiting time is calculated for the EV passing through the entire highway, by jointly considering the charging waiting time at a CS where the EV needs charging for the first time and that time spent at subsequent CSs, before exiting the highway. Other works [?], [?], [?] focus on urban city scenario, where the EV travels towards a single geographically distributed CS for charging. The expected waiting time for charging is associated to that CS, rather than a subsequent charging in high way case.

## III. PROVISIONING OF MEC BASED CHARGING RECOMMENDATION SYSTEM

In this section, we mainly introduce entities and system signalling of the proposed MEC based system, together with analysis on its advantage.

### A. Charging System Cycle

**Driving:** This happens when the EV is travelling on the road (following a route in city).

**Charging Recommendation:** If an EV's remaining electricity is below the State Of Charge (SOC) threshold value, the charging recommendation is required to guide it regarding where to charge.

**Charging Scheduling:** This happens when EVs have reached a CS. The CS implements certain policy to schedule the which EV to be charged. Here, the First Come First Serve (FCFS) is widely applied in the problem of charging recommendation, where the EV with the earliest arrival time is scheduled as the highest priority.

**Battery Charging:** This phase reflects a continuous procedure to charge EVs, until they are fully charged. After that, those fully charged EVs will resume to the **Driving Phase**.

Typically, the system is a status transfer within four phases, while the **Charging Scheduling** has been extensively covered by literature. The focus of this paper is on **Charging Recommendation** with interdisciplinary efforts from ICT.

### B. Network Entities

1) *Stakeholders:* **EV** is below the SOC threshold (a value under which the EV should seek for charging), needs to find a CS for charging. As long as the EV has been recommended to charge at a CS, the EV further reports its charging reservation associated with that CS.

**CS** is equipped with a number of plug-in charging slots, to charge multiple EVs in parallel. Particularly, its local queuing information is monitored by the the cloud server GC, to compute the charging availability. This refers to when the earliest time that a charging slot of CS is unoccupied.

2) *Cloud Server:* It is a logical server that is built and delivered through a cloud computing platform, over CSs and EVs. Here, the **GC** manages the CSs' charging availability, based on the monitored CSs local queueing information, and EVs' charging reservations (collected by MEC servers).

3) *MEC Server:* The MEC servers collocated at RSUs, provide a set of middle-ware services associated to applications, wherein it implements two key operations:

- Disseminate CSs' charging availability (computed by the GC) to EVs.
- Enable information mining, aggregation (complementarily with authentication) for opportunistically collected EVs' charging reservations.

### C. Communication Technologies

As shown in Fig. 1, the communication technology applied between GC and CSs, can be simply based on reliable Internet or cellular network, mainly because they are fixed network entities. However, there is a necessity to scalably and ubiquitously disseminate CSs' charging availability (computed by the GC) to EVs, and collect EVs' charging reservations. Although 3G/LTE can be applied thanks to ubiquitous coverage, EVs' charging requests are just on-demand, while CSs charging availability is fluctuated within certain periods (e.g., minutes-level). Besides, EVs' charging reservations are generated, only

TABLE I  
COMMUNICATION TECHNOLOGIES IN MEC AND CLOUD BASED SYSTEMS

	GC↔MEC Server	GC↔CS	MEC Server↔EV	GC↔EV
MEC Based System	Internet, Cellular network	Internet, Cellular network	WiFi communication	N/A
Cloud Based System	N/A	N/A	N/A	Cellular network

when they have been given the charging recommendation. This motivates to the application of short range and on-demand communication with EVs. Motivated by above, the opportunistic communication paradigm, e.g., Delay/Disruption Tolerant Networking (DTN) [?] between EVs and MEC servers is desirable, which alleviates the burden of solely relying on cellular network. TABLE I summarizes communication technologies in MEC and cloud based systems.

Further, rather than using point-to-point based communication, the topic based communication (e.g., publish/subscribe pattern [?]) mainly offers communications decoupled in space that subscribers do not need to know the location and address of publishers and vice-versa). And it is potentially in time as the system is able to store events for clients which are temporally disconnected.

The solutions to achieve trusted message exchange for EV charging use case is to encrypt the sensitive information and hide the real identity. One development aspect of the encryption involves the light-weight and highly secured encryption algorithm, 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, both are required to be implemented in efficient and scalable manners. The future challenges based on MEC system are considered based on the nature of large number of connected EVs, high mobility, wide coverage area, heterogeneous communication systems.

### D. Proposed MEC Based System

It is assumed that the locations of all CSs are already known by EVs, e.g., through the vehicle On-Board Unit (OBU). Here, EVs access CSs' charging availability from MEC servers, make local charging recommendation and further report charging reservations (through MEC servers to the GC). The GC analyzes the EVs' charging reservations together with CSs' local queuing information, to predict the CSs' charging availability. Fig. 1 illustrates a typical procedure:

**Step 1:** The GC periodically (with time interval  $\Delta$ ) disseminates its computed CSs' charging availability to all legitimate MEC servers (positioned at RSUs), via "*CA\_Update*" topic defined in TABLE II. RSUs further aggregate the information from all CSs, and get cached. Note that the information disseminated at the previous  $\Delta$ , that to be further cached at MEC servers, will be replaced with that associates to current  $\Delta$ . This guarantees the information accuracy involved for charging recommendation. The RSU receiving the dissemination from all CSs, will aggregate and cache their information.

TABLE II  
TOPICS DEFINED IN MEC BASED SYSTEM

Topic	Publisher	Subscriber	Payload
<i>CA_Update</i>	CS	RSUs	<CS ID, CS's charging availability, dissemination time slot>
<i>Aggregated_CA_Update</i>	RSUs	EVs	<Aggregated CS IDs and CSs' charging availability, dissemination time slot>
<i>Charging_Reservations_Update</i>	EVs been recommended charging	RSUs	<EV ID, parking duration, arrival time, expected charging time>
<i>Aggregated_Charging_Reservations_Update</i>	RSUs	GC	<Aggregated EVs' reservations cached by RSUs>
<i>Local_Queueing_Update</i>	CSs	GC	<CS's local queuing information, including number of EVs being parked at CS and their charging time>
<i>CA_Prediction</i>	GC	CSs	<Predicted charging availability of each CS>

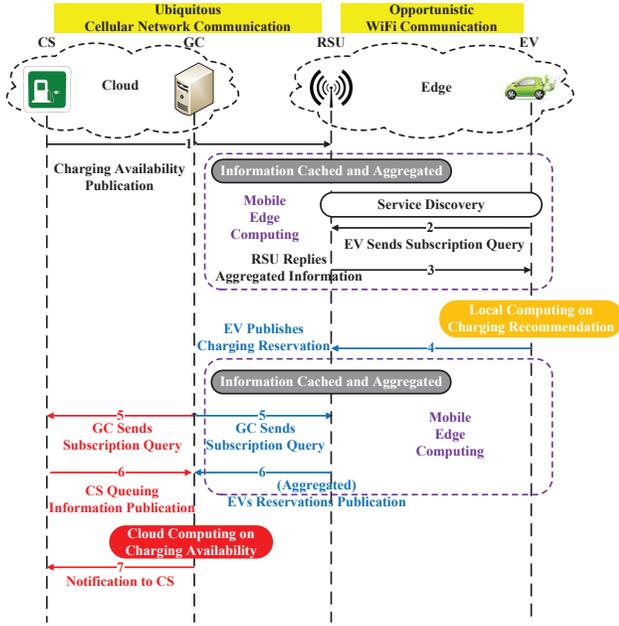


Fig. 1. Signallings Process for MEC System

**Steps 2-3:** Upon encountering with a RSU, the EV would subscribe to the cached information from RSU through P/S system. In particular, the EV only subscribes to the information that is recently published using the “*Aggregated\_CA\_Update*” topic. This reduces the redundant access signalling, particularly when an EV frequently encounters several RSUs in short time (still within the current dissemination interval  $\Delta$ ). For example, if an EV has already obtained information from RSU<sub>1</sub> within interval  $\Delta$ , its subscription will be denied by RSU<sub>2</sub> within the same interval.

**Step 4:** The EV makes charging recommendation in case of low energy status, publishes its charging reservation to any encountered MEC server along the road. Here, the “*Charging\_Reservations\_Update*” topic is applied, with the EV as publisher and RSUs (MEC servers) as subscribers. Each RSU mines valid EV’s charging reservation and aggregates them. The valid charging reservation refers to that of which the EV’s arrival is supposed to be later than  $(\Delta + \mathcal{P})$ , where  $\mathcal{P}$  is the time slot of previous dissemination. This is because an EV’s reservation will be deleted by its selected CS, when it is parked therein. Then any arrival happens before the next dissemination will be removed from RSUs, this potentially reduces the size of data to be uploaded to the GC.

**Steps 5-6:** At the GC side, it sets two separate topics to collect information from CSs and RSUs.

- The local condition of CSs, includes the number EVs being parked and their required battery charging time. Such is accessible by sending a subscription via the “*Local\_Queueing\_Update*” topic.
- The GC also accesses aggregated EVs’ charging reservations from all RSUs, using the “*Aggregated\_Charging\_Reservations\_Update*” topic.

**Step 7:** The GC then predicts the charging availability of CSs, and pushes them for dissemination at the following time slot, using the “*CA\_Prediction*” topic.

#### E. Other Alternative Systems

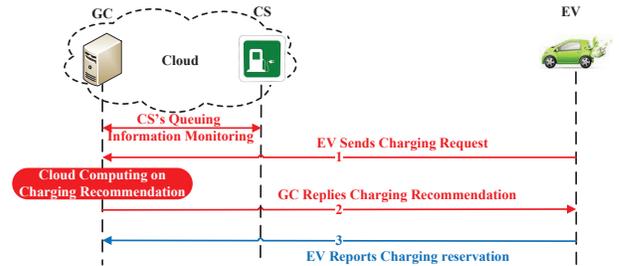


Fig. 2. Signallings Process for CC System

1) *Centralized Cloud (CC) Based System:* It is implemented in a centralized manner in cloud system.

**Step 1:** The EV which needs charging, sends its charging recommendation request to the GC through the cellular network.

**Step 2:** Upon receiving request from an EV, the GC makes charging recommendation based on the intelligence proposed in Section IV, and further reply back to pending EV.

**Step 3:** The EV which accepts the decision then starts a journey towards the recommended CS. In the meanwhile, it reports its charging reservation to the GC, such that the GC can estimate the occultation of reserved CS in a near future.

2) *Decentralized Cloud (DC) Based System:* This is the distributed version of CC based system (based on cellular network), where:

**Step 1:** Each CS periodically (with interval  $\Delta$ ) broadcasts its charging availability to all EVs, also through cellular network communication. This mechanism also equals to the case that each EV subscribes to CS’s charging availability from the GC, through topic based P/S communication, where



TABLE III  
LIST OF NOTATIONS

$\Delta$	Charging availability dissemination interval
$S_{ev}$	Moving speed of EV
$\alpha$	Electric energy consumed per meter
$T_{cur}$	Current time in the network
$\delta$	Number of charging slots at CS
$N_W$	Number of EVs waiting for charging at CS
$N_C$	Number of EVs under charging at CS
$E_{ev}^{max}$	Full volume of EV battery
$E_{ev}^{cur}$	Current volume of EV battery
$\beta$	Charging power at CS
$T_{ev}^{fin}$	Charging finish time of EV
$T_{ev}^{arr}$	EV's arrival time at CS
$T_{ev}^{tra}$	EV's travelling time to reach CS
$T_{ev}^{cha}$	Expected charging time upon arrival of EV
$N_R$	Number of EVs reserved for charging at CS
$\mathcal{W}$	Prediction time window
$\mathcal{H}$	Number of entries within $\mathcal{W}$
$\mathcal{K}$	A time slot of $\mathcal{H}$
$CA_{\mathcal{K}}$	The given charging availability at $\mathcal{K}$
$D_{ev}$	Time duration that EV will park at CS
RLIST	Set including a number EVs made charging reservation at CS
QLIST	Set including available time per charging slot at CS

### A. EV's Charging Reservation

The EV's charging reservation is generated from the EV which had made charging recommendation, and relayed through the MEC servers to the GC. As an example in TALBE IV, such information normally includes the ID of recommended CS, EV's parking deadline, arrival time at that CS, and EV's expected charging time at there, specifically:

**Arrival Time:** The arrival time  $T_{ev}^{arr}$  reflects the time when an EV reaches the recommended CS, where the value counts for the travelling time  $T_{ev}^{tra}$  from the current location of EV to the recommended CS:

$$T_{ev}^{arr} = T_{cur} + T_{ev}^{tra} \quad (2)$$

**Expected Charging Time:** The expected charging time  $T_{ev}^{cha}$  at the selected CS is given by:

$$T_{ev}^{cha} = \frac{E_{ev}^{max} - E_{ev}^{cur} + S_{ev} \times T_{ev}^{tra} \times \alpha}{\beta} \quad (3)$$

Here,  $(S_{ev} \times T_{ev}^{tra} \times \alpha)$  is the energy consumed for movement travelling to the selected CS, based on a constant  $\alpha$  (depending on a certain type EV) measuring the energy consumption per meter.

**Parking Deadline:**  $D_{ev}$  is defined a limitation on how long an EV will stay to wait for charging at the recommended CS.

TABLE IV  
CHARGING RESERVATION FORMAT

EV ID	Selected CS	Parking Deadline	Arrival Time	Expected Charging Time
EV <sub>1</sub>	CS <sub>1</sub>	1200s	17260s	892s

### B. Charging Availability Dissemination

Upon receiving EVs' charging reservations, each GC computes the charging availability for all connected CSs, associat-

ed with a number of time slots  $\mathcal{K}$  that is beyond the interval  $\Delta$ . Here, given that there are predefined  $\mathcal{H}$  time slots associated within  $\mathcal{W}$ , the gap between adjacent  $\mathcal{K}$  time slots is calculated by  $\frac{\mathcal{W}}{\mathcal{H}}$ .

TABLE V  
FORMAT OF CS'S CHARGING AVAILABILITY DISSEMINATION

-CS ID-		
CS <sub>3</sub>		
-Dissemination Time Slot-		
10800s		
-Charging Availability Predicted Within $\mathcal{W}$ -		
Entry	Decoupled Time Slot	Charging Availability
1	10860s	10892s
2	10920s	10920s
3	10980s	10980s

### Algorithm 1 CA-Dissemination

```

1: for ( $i = 1; i \leq \mathcal{H}; i++$ ) do
2:    $\mathcal{K}_i = (T_{cur} + (i - 1) \times \frac{\mathcal{W}}{\mathcal{H}})$ 
3:   if ( $N_R \neq 0$ ) then
4:     sort the queue of  $N_R$  according to FCFS
5:     for ( $j = 1; j \leq N_R; j++$ ) do
6:       if ( $T_{ev(j)}^{arr} < \mathcal{K}_i$ ) then
7:         add EVj into RLIST
8:       end if
9:     end for
10:    if ( $|RLIST| \neq 0$ ) then
11:       $CA_{\mathcal{K}_i} = \text{CA-Prediction}(RLIST, \mathcal{K}_i)$  via Algorithm 4
12:    else
13:       $CA_{\mathcal{K}_i} = \text{CA-Prediction}(\mathcal{K}_i)$  via Algorithm 3
14:    end if
15:  else
16:     $CA_{\mathcal{K}_i} = \text{CA-Prediction}(\mathcal{K}_i)$  via Algorithm 3
17:  end if
18:  add  $\langle \mathcal{K}_i, CA_{\mathcal{K}_i} \rangle$  in entry  $i$ 
19: end for

```

Algorithm 1 is implemented by the GC, and disseminates information formatted in TABLE V. The time slot at the  $i^{th}$  entry, is calculated by  $\mathcal{K}_i = (T_{cur} + (i - 1) \times \frac{\mathcal{W}}{\mathcal{H}})$ , where  $T_{cur}$  is the current time in network. Understandably,  $\mathcal{K}_i$  indicates a time slot beyond the current network time  $T_{cur}$ . A entire process of CS's information dissemination is presented as follows:

- The EV<sub>j</sub> (in the queue of  $N_R$ ) which has reported charging reservation to the recommended CS (while its arrival time  $T_{ev(j)}^{arr}$  is earlier than the  $\mathcal{K}_i$ ), will be recorded into a list, namely RLIST. Here, we consider there will be other EVs (in the queue of  $N_R$ ) reserve and reach at the same CS, before the the time slot  $\mathcal{K}_i$  as the condition  $(T_{ev(j)}^{arr} < \mathcal{K}_i)$  at line 6. In this context, the charging availability estimated at  $\mathcal{K}_i$ , as denoted by  $CA_{\mathcal{K}_i}$  is calculated via Algorithm 4.

Note that, at line 11, the predicting of CS's charging availability via Algorithm 4 requires an input of charging reservations of those EV<sub>j</sub> with an earlier arrival time than  $\mathcal{K}_i$ . This is given by the condition at line 10 in Algorithm 1. Otherwise, Algorithm 3 is applied by only examining the local conditions of CSs (e.g., number of EVs being parked and remaining charging time)

- Alternatively, Algorithm 3 is also applied if there has not been EVs' charging reservations, as presented between lines 15 and 16.

Then, a pair of  $\langle \mathcal{K}_i, CA_{\mathcal{K}_i} \rangle$  stating the "(time slot, charging availability at time slot)" will be prepared for dissemination. The information is then disseminated as the Step 1 in Fig. 1.

### C. Dynamic Update of $\mathcal{W}$

Note that, the  $\mathcal{W}$  is updated based on a dynamic adaption mechanism. This is triggered by the event that an EV is making charging reservations at the recommended CS within time slot  $\mathcal{K}$ , then the travelling time  $T_{ev}^{tra}$  of EV is compared with the value of estimation window  $\mathcal{W}$  that is currently applied in charging system. The larger value is updated as new estimation window of  $\mathcal{W}$ .

The advantage is to gradually learn the charging demand distribution of EVs. This is to say, if most of EVs are with shorter  $T_{ev}^{tra}$  towards CSs recommended to them, a much urgent charging will be prepared. As such, the way to predict the CSs' charging availability will be with a tight  $\mathcal{W}$  (or say smaller  $\mathcal{W}$ ), such that the accuracy is adjusted with  $\frac{\mathcal{W}}{\mathcal{H}}$ .

### D. Prediction of Charging Availability Without EVs' Charging Reservations

Here, as no EVs' charging reservations are available, the charging availability is computed solely based on the CS' local queueing information. A set QLIST is defined, to represent the available time of all charging slots locally at a CS.

1) *Generation of QLIST*: As each CS has  $\delta$  charging slots to charge parked EVs in parallel, we consider two types of queues localized at CS. Here, EVs being charged are included in the queue of  $N_C$ , while those waiting for charging (due to all  $\delta$  charging slots of a CS have been occupied by other EVs for charging) are characterized in the queue of  $N_W$ .

From line 1 at Algorithm 2, for each EV<sub>*i*</sub> being charged, the time length  $\left(\frac{E_{ev(i)}^{max} - E_{ev(i)}^{cur}}{\beta}\right)$  to fully recharge its battery (in the queue of  $N_C$ ), will be compared with its parking duration  $D_{ev(i)}$ . The comparison outcome is applied to estimate the time that EV<sub>*i*</sub> will finish its charging:

- In one case, the condition  $\left(\left(T_{cur} - T_{ev(i)}^{arr} + \frac{E_{ev(i)}^{max} - E_{ev(i)}^{cur}}{\beta}\right) \leq D_{ev(i)}\right)$  implies this EV<sub>*i*</sub> can be fully recharged before departure. Here,  $(T_{cur} - T_{ev(i)}^{arr})$  is the time duration to wait for charging since the arrival of EV<sub>*i*</sub>. As such, at line 3, the charging finish time (about when the charging of EV<sub>*i*</sub> will finish)  $T_{ev(i)}^{fin}$  of EV<sub>*i*</sub> is given by a summation of  $\left(\frac{E_{ev(i)}^{max} - E_{ev(i)}^{cur}}{\beta} + T_{cur}\right)$  only.
- In another case,  $T_{ev(i)}^{fin}$  is given by  $(T_{ev(i)}^{arr} + D_{ev(i)})$  at line 5, as the time slot that EV<sub>*i*</sub> leaves from CS.

Further to above, the presentation between lines 8 and 12 reflects a case that not all  $\delta$  charging slots have been occupied by other EVs for charging. Therefore, it is easy to determine

that there are still  $(\delta - N_C)$  slots can be reserved by incoming EVs for charging. As such, the available charging time for these unoccupied charging slots is all unified as  $T_{cur}$ .

### Algorithm 2 Generation of QLIST

---

```

1: for ( $i = 1; i \leq N_C; i++$ ) do
2:   if  $\left(\left(T_{cur} - T_{ev(i)}^{arr} + \frac{E_{ev(i)}^{max} - E_{ev(i)}^{cur}}{\beta}\right) \leq D_{ev(i)}\right)$  then
3:     add  $\left(\frac{E_{ev(i)}^{max} - E_{ev(i)}^{cur}}{\beta} + T_{cur}\right)$  into QLIST
4:   else
5:     add  $(T_{ev(i)}^{arr} + D_{ev(i)})$  into QLIST
6:   end if
7: end for
8: if  $(N_C < \delta)$  then
9:   for ( $j = 1; j \leq (\delta - N_C); j++$ ) do
10:    add  $(T_{cur})$  into QLIST
11:   end for
12: end if
13: sort the queue of  $N_W$  according to FCFS
14: for ( $k = 1; k \leq N_W; k++$ ) do
15:   sort QLIST with ascending order
16:   if  $\left(\left(QLIST_1 - T_{ev(k)}^{arr}\right) < D_{ev(k)}\right)$  then
17:     if  $\left(\left(QLIST_1 - T_{ev(k)}^{arr} + \frac{E_{ev(k)}^{max} - E_{ev(k)}^{cur}}{\beta}\right) \leq D_{ev(k)}\right)$  then
18:        $T_{ev(k)}^{fin} = \left(QLIST_1 + \frac{E_{ev(k)}^{max} - E_{ev(k)}^{cur}}{\beta}\right)$ 
19:     else
20:        $T_{ev(k)}^{fin} = (T_{ev(k)}^{arr} + D_{ev(k)})$ 
21:     end if
22:     replace  $QLIST_1$  with  $T_{ev(k)}^{fin}$  in LIST
23:     sort QLIST with ascending order
24:   end if
25: end for
26: return QLIST

```

---

Then, Algorithm 2 firstly sorts the queue of  $N_W$  based on FCFS order, by following the charging scheduling Section III. Besides, the QLIST that includes those EVs under charging will be sorted with ascending order. Here, the earliest available time for charging at a CS is the deemed as the first element in QLIST, and we denote that time as  $QLIST_1$  (the first element of sorted QLIST).

In detail, to calculate the charging finish time  $T_{ev(k)}^{fin}$  of each EV<sub>*k*</sub> (in the queue of  $N_W$ ), requires to know the earliest available time of charging slots. In principal, it is crucial to consider the EV<sub>*k*</sub> which at least will be charged during its parking duration  $D_{ev(k)}$  to involve calculation. This constraint is defined by  $\left(\left(QLIST_1 - T_{ev(k)}^{arr}\right) < D_{ev(k)}\right)$  at line 16.

- Then from lines 17 and 21, either  $\left(QLIST_1 + \frac{E_{ev(k)}^{max} - E_{ev(k)}^{cur}}{\beta}\right)$  or  $(T_{ev(k)}^{arr} + D_{ev(k)})$  calculates the  $T_{ev(k)}^{fin}$ , in particular  $(QLIST_1 - T_{ev(k)}^{arr})$  is referred as the for EV<sub>*k*</sub> to wait for charging.
- Upon the  $T_{ev(k)}^{fin}$  been given, the  $QLIST_1$  will be replaced with  $T_{ev(k)}^{fin}$ . Then, the QLIST will be resorted with ascending order upon processing each EV<sub>*k*</sub> in the loop.

The above loop operation is finished when all EV<sub>*k*</sub> (in the queue of  $N_W$ ) have been processed, and an updated QLIST is generated.

2) *Charging Availability Computing*: Based on Algorithm 2 with QLIST being generated, CS's local queueing information is computed to predict the charging availability associated with

**Algorithm 3** CA-Prediction ( $\mathcal{K}$ )

---

```

1: sort QLIST from Algorithm 2 in ascending order
2: if  $QLIST_1 > \mathcal{K}$  then
3:   return  $QLIST_1$ 
4: else
5:   return  $\mathcal{K}$ 
6: end if

```

---

$\mathcal{K}$  in Algorithm 3. Here, as the  $QLIST_1$  is later than  $\mathcal{K}$ , the charging availability is represented as  $QLIST_1$ , and otherwise as  $\mathcal{K}$ . This depends on whether the CS will be available for charging at the time slot  $\mathcal{K}$ .

*E. Prediction of Charging Availability With EVs' Charging Reservations*

Recall that Algorithm 1 has already included a number of EVs into the RLIST, which is an input for Algorithm 4. This guarantees the charging availability of CS is predicted, by tracking the EVs will reach the reserved CS within  $\frac{\mathcal{W}}{\mathcal{H}}$  and the charging time of EVs been parked at there. Here, the latter information is provided by QLIST generated via Algorithm 2 and sorted based on the ascending order.

At line 5 in Algorithm 4, for each  $EV_i$  (in the queue of  $N_R$ ) with its  $T_{ev(i)}^{arr}$  prior to the earliest available time for charging  $QLIST_1$ ,  $EV_i$  will be taken into account for the update of the QLIST. This means only those EVs (in the queue of  $N_R$ ) arrives later than  $QLIST_1$  will not have influence on the QLIST. Note that the QLIST has been previously sorted according to the ascending order. This guarantees that the earliest time that one of charging slots will be free, is ready for taking the subsequent EV's charging.

**Algorithm 4** CA-Prediction (RLIST,  $\mathcal{K}$ )

---

```

1: sort the queue of  $N_R$  according to FCFS
2: sort QLIST returned by Algorithm 2, with ascending order
3: for ( $i = 1; i \leq N_R; i++$ ) do
4:   if RLIST contains  $EV_i$  then
5:     if ( $QLIST_1 > T_{ev(i)}^{arr}$ ) then
6:       if ( $(QLIST_1 - T_{ev(i)}^{arr}) < D_{ev(i)}$ ) then
7:         if ( $(QLIST_1 - T_{ev(i)}^{arr} + T_{ev(i)}^{cha}) \leq D_{ev(i)}$ ) then
8:            $T_{ev(i)}^{fin} = (QLIST_1 + T_{ev(i)}^{cha})$ 
9:         else
10:           $T_{ev(i)}^{fin} = (T_{ev(i)}^{arr} + D_{ev(i)})$ 
11:        end if
12:      end if
13:    else
14:      if ( $T_{ev(i)}^{cha} \leq D_{ev(i)}$ ) then
15:         $T_{ev(i)}^{fin} = (T_{ev(i)}^{arr} + T_{ev(i)}^{cha})$ 
16:      else
17:         $T_{ev(i)}^{fin} = (T_{ev(i)}^{arr} + D_{ev(i)})$ 
18:      end if
19:    end if
20:    replace the  $QLIST_1$  with  $T_{ev(i)}^{fin}$ 
21:    sort QLIST with ascending order
22:  end if
23: end for
24: if ( $QLIST_1 > \mathcal{K}$ ) then
25:   return  $QLIST_1$ 
26: else
27:   return  $\mathcal{K}$ 
28: end if

```

---

- In one case, the condition ( $QLIST_1 > T_{ev(i)}^{arr}$ ) at line 5 implies that  $T_{ev(i)}^{arr}$  is prior to the earliest available time  $LIST_1$ . This causes the charging finish time  $T_{ev(i)}^{fin}$  is to be calculated by summing  $QLIST_1$  and the expected charging time  $T_{ev(i)}^{cha}$ .

In particular, at line 7 the condition ( $(QLIST_1 - T_{ev(i)}^{arr} + T_{ev(i)}^{cha}) \leq D_{ev(i)}$ ) implies that, within the parking duration the  $D_{ev(i)}$  the  $EV_i$  could be fully recharged. Recall that  $(QLIST_1 - T_{ev(i)}^{arr})$  is the time to wait until the charging is started. In this context, given by the cases at lines 7 and 9,  $T_{ev(i)}^{fin}$  is given by  $(QLIST_1 + T_{ev(i)}^{cha})$  or  $(T_{ev(i)}^{arr} + D_{ev(i)})$ . Note that, as the condition given by  $(QLIST_1 - T_{ev(i)}^{arr}) < D_{ev(i)}$  at line 6, we only consider the  $EV_i$  could be charged before  $D_{ev(i)}$  to involve the calculation.

- In another case,  $T_{ev(i)}^{fin}$  is calculated by considering  $T_{ev(i)}^{arr}$ ,  $T_{ev(i)}^{cha}$  and  $D_{ev(i)}$  following the calculations at lines 15 and 17. This only happens when  $(QLIST_1 \leq T_{ev(i)}^{arr})$ , meaning that the CS has already been available charging when  $EV_i$  arrives.

By replacing the  $QLIST_1$  with each  $T_{ev(i)}^{fin}$  in each loop round, the QLIST will be dynamically updated. Further, the QLIST will be sorted with the ascending order after the process of each  $EV_i$ , such that the first element  $QLIST_1$  is updated. The loop operation ends when all  $EV_i$  (in the queue of  $N_R$ ) have been processed.

*F. Charging Recommendation*

Here,  $EV_r$  is denoted as the EV needs to make charging recommendation, other than those EVs that are either being parked or on-the-move. Two bounding time slots can be obtained via the condition at line 2 of Algorithm 5, such that the arrival time of  $EV_r$ , denoted as  $T_{ev(r)}^{arr}$  is between these two time slots  $\mathcal{K}_i$  and  $\mathcal{K}_{i+1}$ . In this case, the outcome of charging availability is then passed to a temporary variable  $\mathcal{A}$ , with  $\mathcal{A} = \left( CA_{\mathcal{K}_i} + \frac{T_{ev(r)}^{arr} \times (CA_{\mathcal{K}_{i+1}} - CA_{\mathcal{K}_i})}{\mathcal{K}_{i+1}} \right)$  at line 3, considering a ratio between  $T_{ev(r)}^{arr}$  and  $\mathcal{K}_{i+1}$ . From this calculation, it is aimed to capture the charging availability, upon its arrival time  $EV_r$  that is between  $\mathcal{K}_i$  and  $\mathcal{K}_{i+1}$ .

There are also two cases if  $T_{ev(r)}^{arr}$  is out of the bound of the estimation window  $\mathcal{W}$ :

- Due to that  $T_{ev(r)}^{arr}$  is earlier than the earliest estimation time slot in entries  $\mathcal{H}$ , denoted as  $\mathcal{K}_1$ , the charging availability upon the arrival of  $EV_r$  is given by  $CA_{\mathcal{K}_1}$  at line 7.
- Besides, due to that  $T_{ev(r)}^{arr}$  is later than the latest time slot in entries  $\mathcal{H}$ , the charging availability in this case is given by  $CA_{\mathcal{K}_{(\mathcal{H})}}$  at line 9.

Next, the  $EV_r$  will predict an expected time it would stay at recommended CS before the parking deadline, by considering its parking duration  $D_{ev(r)}$ .

- Basically, if  $EV_r$  arrives later than  $\mathcal{A}$ , this means it still needs to wait for additional time until a

**Algorithm 5** Charging Recommendation Strategy

---

```

1: for ( $i = 1; i \leq (\mathcal{H} - 1); i++$ ) do
2:   if ( $\mathcal{K}_i \leq T_{ev(r)}^{arr}$ ) && ( $\mathcal{K}_{i+1} > T_{ev(r)}^{arr}$ ) then
3:      $\mathcal{A} = \left( CA_{\mathcal{K}_i} + \frac{T_{ev(r)}^{arr} \times (CA_{\mathcal{K}_{i+1}} - CA_{\mathcal{K}_i})}{\mathcal{K}_{i+1}} \right)$ 
4:   end if
5: end for
6: if ( $\mathcal{K}_1 > T_{ev(r)}^{arr}$ ) then
7:    $\mathcal{A} = CA_{\mathcal{K}_1}$ 
8: else if ( $\mathcal{K}_H \leq T_{ev(r)}^{arr}$ ) then
9:    $\mathcal{A} = CA_{\mathcal{K}_H}$ 
10: end if
11: if ( $\mathcal{A} > T_{ev(r)}^{arr}$ ) then
12:   if ( $\mathcal{A} - T_{ev(r)}^{arr} + T_{ev(r)}^{cha} \leq D_{ev(r)}$ ) then
13:     return  $\mathcal{A} - T_{ev(r)}^{arr} + T_{ev(r)}^{cha}$ 
14:   else
15:     return  $D_{ev(r)}$ 
16:   end if
17: else
18:   if ( $T_{ev(r)}^{cha} \leq D_{ev(r)}$ ) then
19:     return  $T_{ev(r)}^{cha}$ 
20:   else
21:     return  $D_{ev(r)}$ 
22:   end if
23: end if

```

---

charging slot is available. In this case, the condition  $(\mathcal{A} - T_{ev(r)}^{arr} + T_{ev(r)}^{cha} \leq D_{ev(r)})$  indicates  $EV_r$  can be fully recharged within parking deadline  $D_{ev(r)}$ , thus its expected staying time is calculated by  $(\mathcal{A} - T_{ev(r)}^{arr} + T_{ev(r)}^{cha})$  at line 13. Otherwise, only the  $D_{ev(r)}$  is referred as the staying time at line 14.

- Such a policy between lines 18 and 22 can be also applied to the case, if  $EV_r$  arrives no later than  $\mathcal{A}$ . In this case, as  $EV_r$  does not need to wait for additional time to start charging, the comparison is just between  $T_{ev(r)}^{arr}$  and  $D_{ev(r)}$ .

## V. PERFORMANCE EVALUATION

### A. Scenario Configuration

The entire system for EV charging is built in Opportunistic Network Environment (ONE) [?]. In Fig. 5, the default scenario with  $4500 \times 3400 m^2$  area is shown as the downtown area of Helsinki city in Finland.  $N_{ev} = 300$  EVs with  $S_{ev} = [30 \sim 50] km/h$  variable moving speed are initialized considering road safety in a city. The configuration of EVs follows the charging specification of **Hyundai BlueOn**, with maximum electricity capacity 16.4 kWh, max travelling distance 140 km, SOC  $[15 \sim 45]\%$ . Besides,  $N_{cs} = 5$  CSs are provided with sufficient electric energy and  $\delta = 5$  charging slots through entire simulation, using the fast charging rate of  $\beta = 62kW$ .  $R = 300m$  radio coverage is applied for  $N_{mec} = 7$  RSUs and  $N_{ev} = 300$  EVs. The default dissemination interval of CS's charging availability is  $\Delta = 120s$ , and the simulation time is  $43200s = 12$  hours.

The following schemes are evaluated for comparison:

- **MEC**: The proposed charging recommendation scheme in Section IV, based on the MEC framework in III.

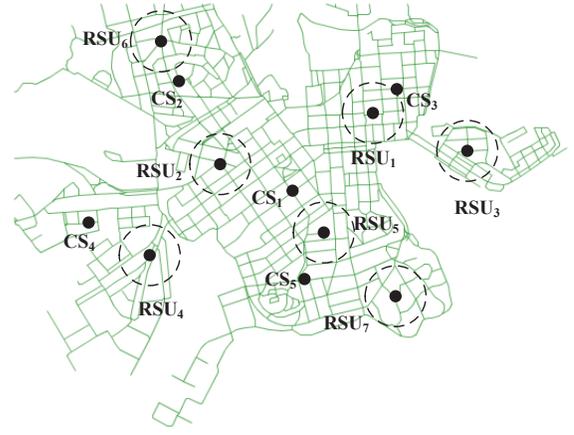


Fig. 5. The Helsinki City Scenario

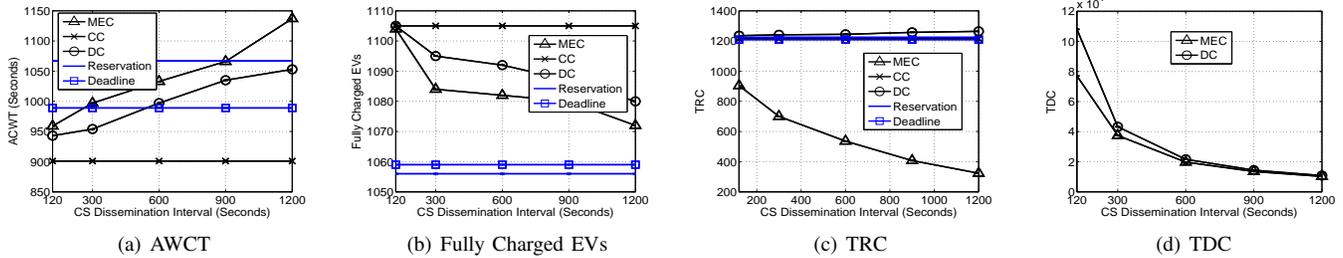
- **CC & DC**: They are with the same charging recommendation scheme with MEC, but with centralized and distributed cloud computing framework.
- **Reservation** [?]: Previous work takes the EVs' charging reservation to predict the CSs' charging availability, however not addressing the EVs' parking deadline. Here, the cloud computing framework is positioned.
- **Deadline** [?]: Previous work taking the parking deadline into the account of charging recommendation, based on the cloud computing framework. This scheme differs from CC for the computation intelligence to predict CSs' charging availability.

The simulation evaluates metrics at EV and CS sides, as well as communication costs at system level:

- **Average Charging Waiting Time (ACWT)**: The average period between the time an EV arrives at the recommended CS and the time it finishes (full) recharging its battery. This is the performance metric at the EV side.
- **Fully Charged EVs**: The total number of fully charged EVs, this is the performance metric at the CS side.
- **Total Reservation Cost (TRC)**: The total number signalling reported for EV's charging reservations to the GC. In MEC, this counts for the signalling from RSUs to the GC, while other schemes counts from EVs to the GC.
- **Total Dissemination Cost (TDC)**: In MEC, this counts for the signalling from RSUs to the EVs, while in DC this counts from GC to EVs.

### B. Performance Results

1) *Influence of CS Dissemination Interval  $\Delta$* : Results in Fig. 6(a) and Fig. 6(b) show that a frequent dissemination interval helps to maintain the optimality of charging recommendation. This refers to that as the information is replaced at RSUs frequently, EVs passed by would fetch the cached information that is more fresh. In comparison to DC, the CC achieves the best performance, due to making decision using seamless cellular network communication, compared to the opportunistic communication between RSUs and EVs as applied in MEC system. Further, concerning the feature of charging recommendation, the CC outperforms Reservation

Fig. 6. Influence of CS Dissemination Interval  $\Delta$ 

and Deadline, thanks to decoupling the decision making within a small time interval  $\mathcal{W}$ . It is also observed that the Deadline outperforms Reservation, as the former takes the EVs' parking deadline into account.

In Fig. 6(c), MEC base system is with decreased TRC, which follows the analysis in Section III. While, other compared charging recommendations with cloud based system are with much higher TRC. The benefit of reduced TRC is from the aggregation and mining functions at RSUs, which filter invalid EVs' charging reservations (that to be not uploaded to the GC) for computation. Besides, the dissemination cost is shown in Fig. 6(d), where the cost in MEC is lower than in DC based systems (with  $\Delta = 120s$ ). This shows the efficiency of using on-demand and short range wireless communication in MEC based system together with access control, compared to the long range cellular link and broadcasting communication in DC based system. In following subsections, DC is excluded, while only the nature of charging recommendation solutions is discussed.

2) *Influence of Parking Deadline  $D_{ev}$* : In Fig. 7(b), a longer parking deadline  $D_{ev}$  increases the fully charged EVs. This is generally referred to the situation that EVs being parked at CSs will have much chance to be fully charged, compared to the case with 1200s parking deadline. While, such increase brings increased ACWT in Fig. 7(a) as well. In Fig. 7(c), it is observed that a shorter parking deadline leads to a much higher TRC. This is because of those EVs not fully charged will subsequently need charging after shorter period. As such the charging reservation is increased corresponds to such frequent charging demand.

Apart from above general observation, further details are comparable in case of 5 and 7 charging slots. The latter case alleviates the charging congestion at CSs, as such it delivers a lower ACWT and higher fully charged EVs, as well as reduced TRC (more significant in case of 1200s parking deadline).

3) *Influence of EV Density  $N_{ev}$* : In Fig. 8(a) the ACWT is increased from the case of 100 EVs, as more EVs will be fully charged (with 300 and 500 EVs). However, Fig. 8(b) shows the the fully charged EVs is firstly increased from 100 to 300 EVs cases, whereas decreases from 300 to 500 EVs cases. This reflects the 500 EVs case results in severe charging congestion, as such some EVs are not fully charged. Such an outcome is also associated with the TRC, wherein Fig. 8(c) shows the TRC in case of 500 EVs, is much higher than the fully charged EVs in the same case of Fig. 8(b). The mismatch is from the EVs which were not fully charged but latter needs

charging (with additional charging reservations sent).

If applying 7 charging slots per CS, where the fully charged EVs is increased in Fig. 9(b), along with increased ACWT in Fig. 9(a). Compared with that in Fig. 8(b) where there is a decrease for fully charged EVs from 300 to 500 EVs cases, the situation here implies the effect of parking deadline with limited charging infrastructures. Of course, the MEC based system still achieves the lowest TRC in Fig. 9(c), similar to previous observation.

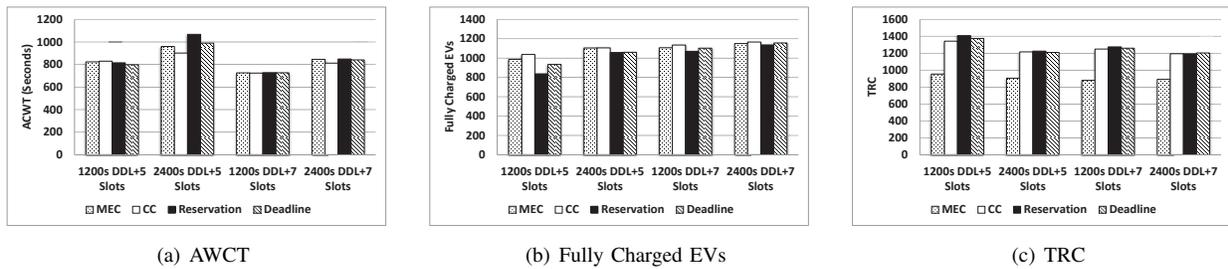
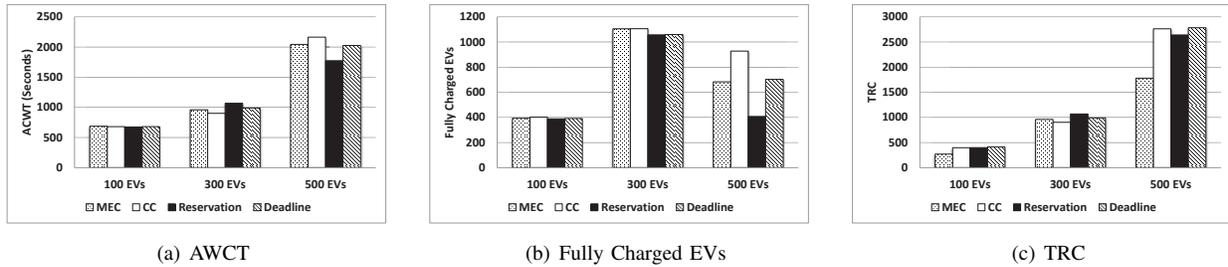
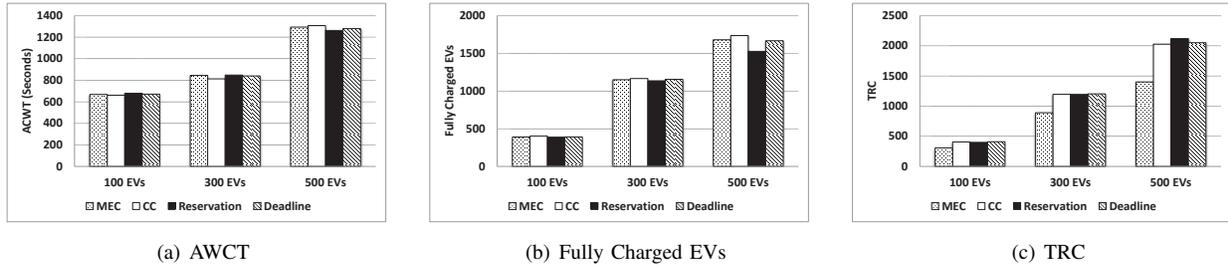
## VI. CONCLUSION

This paper investigated EV charging recommendation via MEC architecture, with RSUs positioned physically and MEC functions virtually to help with information dissemination and collection. The information access control, aggregation and mining are enabled at MEC servers, while the charging recommendation takes the EV's charging reservation and its parking deadline into account. Results show the proposed solution achieves a comparable performance, in terms of charging waiting time as benefit at user side, and number of fully charged EVs as benefit at service provide side. Future works would be on integration of power network.

With the ever increasing 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. Coordination of the charging energy with renewable energy source provides a more straightforward approach to cope with the potential network issues as mentioned above. Future works would be on the integration of power network to achieve an interdisciplinary work on ICT, route planning and energy integration.

## REFERENCES

- [1] Y. Cao, N. Wang, G. Kamel, and Y.-J. Kim, "An Electric Vehicle Charging Management Scheme Based on Publish/Subscribe Communication Framework," *IEEE Systems Journal*, vol. 11, no. 3, pp. 1822–1833, September, 2017.
- [2] J. C. Mukherjee and A. Gupta, "A review of charge scheduling of electric vehicles in smart grid," *IEEE Systems Journal*, vol. 9, no. 4, pp. 1541–1553, December 2015.
- [3] E. Rigas, S. Ramchurn, and N. Bassiliades, "Managing Electric Vehicles in the Smart Grid Using Artificial Intelligence: A Survey," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 4, pp. 1619–1635, August, 2015.
- [4] S.-N. Yang, W.-S. Cheng, Y.-C. Hsu, C.-H. Gan, and Y.-B. Lin, "Charge Scheduling of Electric Vehicles in Highways," *Elsevier Mathematical and Computer Modelling*, vol. 57, no. 1112, pp. 2873 – 2882, June, 2013.

Fig. 7. Influence of EVs' Parking Deadline  $D_{ev}$ Fig. 8. Influence of EVs Density  $N_{ev}$ , with  $\delta = 5$  Charging SlotsFig. 9. Influence of EVs Density  $N_{ev}$ , with  $\delta = 7$  Charging Slots

- [5] M. Gharbaoui, L. Valcarengi, R. Bruno, B. Martini, M. Conti, and P. Castoldi, "An Advanced Smart Management System for Electric Vehicle Recharge," in *IEEE IEVC' 2012*, Greenville, SC, USA, March, 2012.
- [6] F. Hausler, E. Crisostomi, A. Schlote, I. Radosch, and R. Shorten, "Stochastic Park-and-Charge Balancing for Fully Electric and Plug-in Hybrid Vehicles," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 2, pp. 895–901, April, 2014.
- [7] Y. Cao, N. Wang, and G. Kamel, "A Publish/Subscribe Communication Framework For Managing Electric Vehicle Charging," in *IEEE ICCVE' 14*, Vienna, Austria, November, 2014.
- [8] Q. T. and Kezhi Wang, Y. sheng Luo, and K. Yang, "Congestion balanced green charging networks for electric vehicles in smart grid," in *IEEE ICC 2017*, paris, France, 2017.
- [9] H. Qin and W. Zhang, "Charging Scheduling With Minimal Waiting in a Network of Electric Vehicles and Charging Stations," in *ACM VANET ' 11*, Las Vegas, Nevada, USA, September, 2011.
- [10] Y. Cao, O. Kaiwartya, R. Wang, T. Jiang, Y. Cao, N. Aslam, and G. Sexton, "Towards Efficient, Scalable and Coordinated On-the-move EV Charging Management," *IEEE Wireless Communications*, vol. 24, no. 2, pp. 66–73, April, 2017.
- [11] Y. Cao, T. Wang, O. Kaiwartya, G. Min, N. Ahmad, and A. H. Abdullah, "An EV Charging Management System Concerning Drivers' Trip Duration and Mobility Uncertainty," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 48, no. 4, pp. 596–607, April 2016.
- [12] G. Jia, G. Han, J. Jiang, N. Sun, and K. Wang, "Dynamic Resource Partitioning for Heterogeneous Multi-Core-Based Cloud Computing in Smart Cities," *IEEE Access*, vol. 4, pp. 108–118, 2016.
- [13] M. T. Beck, M. Werner, S. Feld, and S. Schimper, "Mobile edge computing: A taxonomy," in *Proc. of the Sixth International Conference on Advances in Future Internet*. Citeseer, 2014.
- [14] M. Rashidi, I. Batros, T. Madsen, M. Riaz, and T. Paulin, "Placement of Road Side Units for Floating Car Data Collection in Highway Scenario," in *IEEE ICUM' 12*, Petersburg, Russia, October, 2012.
- [15] K. Ghaffoor, J. Lloret, K. Bakar, A. Sadiq, and S. Mussa, "Beaconing approaches in vehicular ad hoc networks: a survey," *Wireless Personal Communications*, vol. 73, no. 3, pp. 885–912, 2013.
- [16] A. Delia, F. Viola, F. Montori, M. D. Felice, L. Bedogni, L. Bononi, A. Borghetti, P. Azzoni, P. Bellavista, D. Tarchi, R. Mock, and T. S. Cinotti, "Impact of interdisciplinary research on planning, running, and managing electromobility as a smart grid extension," *IEEE Access*, vol. 3, pp. 2281–2305, 2015.
- [17] L. Bedogni, L. Bononi, M. D. Felice, A. D'Elia, R. Mock, F. Morandi, S. Rondelli, T. S. Cinotti, and F. Vergari, "An integrated simulation framework to model electric vehicle operations and services," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 8, pp. 5900–5917, Aug 2016.
- [18] Y. Cao, C. Long, T. Jiang, and S. Mao, "Share communication and computation resources on mobile devices: a social awareness perspective," *IEEE Wireless Communications*, vol. 23, p. 5259, August 2016.
- [19] Y. Cao and Z. Sun, "Routing in Delay/Disruption Tolerant Networks: A Taxonomy, Survey and Challenges," *IEEE Communications Surveys Tutorials*, vol. 15, no. 2, pp. 654–677, Second Quarter, 2013.
- [20] P. T. Eugster, P. A. Felber, R. Guerraoui, and A.-M. Kermarrec, "The Many Faces of Publish/Subscribe," vol. 35, no. 2, pp. 114–131, June, 2003.
- [21] A. Keränen, J. Ott, and T. Kärkkäinen, "The ONE Simulator for DTN Protocol Evaluation," in *ICST SIMUTools '09*, Rome, Italy, March, 2009.



**Yue Cao** received the PhD degree from the Institute for Communication Systems (ICS), 5G Innovation Centre (SGIC), at University of Surrey, Guildford, UK in 2013. He was a Research Fellow at the ICS until September 2016, and Lecturer in Department of Computer and Information Sciences, at Northumbria University, Newcastle upon Tyne, UK until July 2017, and currently the Senior Lecturer since August 2017. His research interests focus on Intelligent Mobility. He is the Associate Editor of IEEE Access and International Journal of Vehicular Telematics

and Infotainment Systems.



**Jaime Lloret** received his M.Sc. in Physics in 1997, his M.Sc. in electronic Engineering in 2003 and his Ph.D. in telecommunication engineering in 2006. He is currently Associate Professor at the Universitat Politècnica de Valencia, Spain. He was the Chair of the Internet Technical Committee (IEEE Communications Society and Internet society) and Working Group of the Standard IEEE 1907.1. He is editor-in-chief of the Ad Hoc and Sensor Wireless Networks, and associate editor of 46 international journals (16 ISI).



**Omprakash Kaiwartya** received his Ph.D. degree in Computer Science from School of Computer and Systems Sciences, Jawaharlal Nehru University, New Delhi, India in 2015. He is currently a Lecturer at the School of Science and Technology, Nottingham Trent University, UK since May, 2018. He was a Research Associate at the Department of Computer and Information Sciences, Northumbria University, UK in 2017, and a Postdoctoral Research Fellow at the Faculty of Computing, Universiti Teknologi Malaysia, Johor Bahru in 2016. His research inter-

ests focus on Internet of connected Vehicles, Electronic Vehicles Charging Management, and IoT use cases in Sensor Networks.



**Yuan Zhuang** received his bachelors degree in information engineering and masters degree in micro-electronics and solid-state electronics from Southeast University, Nanjing, China, in 2008 and 2011, respectively, and Ph.D. degree in geomatics engineering from the University of Calgary, Canada, in 2015. He is currently Lead Scientist in Bluvision Inc. (a part of HID Global). His current research interests include IoT-based asset tracking and condition monitoring, real time location system, pedestrian navigation, and multisensors integration.



**Naveed Ahmad** received his BSc (Computer Sciences) honors degree from University of Peshawar, Pakistan in 2007, and PhD in Electronics and Electrical Engineering from Institute of Communication System, University of Surrey, UK in 2013. He is currently serving as Assistant Professor in Department of Computer Science, University of Peshawar, Pakistan. He research interests include routing, security and privacy in emerging networks such as Vehicular Adhoc Networks (VANETS), Delay Tolerant Networks (DTN) and Internet of Things (IoT).



**Yan Sun** received the B.Eng. degree in telecommunications engineering from the Beijing University of Posts and Telecommunications, Beijing, China, in 2001, and the M.Sc. and Ph.D. degrees in electronic engineering from Queen Mary University of London, London, U.K., in 2003 and 2009, respectively. She joined Siemens Ltd., China, in 2001, as a Network Optimization Engineer, and rejoined in 2003, as a System Engineer in R&D after obtaining her master degree in the U.K. She then worked with Siemens (later Nokia Siemens Networks, Ltd.), as a Product

Manager. In 2009, she returned to Queen Mary University of London, as a Lecturer. Her current research interests include ad hoc networks, software-defined networks, and mobile healthcare networks.