Northumbria Research Link

Electric Vehicle Charging Recommendation and Enabling ICT Technologies: Recent Advances and Future Directions

Yue Cao[1], Houbing Song[2], Omprakash Kaiwartya[1], Ao Lei[4], Yue Wang[1] and Ghanim Putrus[1]

[1]Department of Computer and Information Sciences, Northumbria University, UK

[1]yue.cao; omprakash.kaiwartya; yue5.wang; ghanim.putrus@northumbria.ac.uk

[2]Department of Electrical, Computer, Software, and Systems Engineering, Embry-Riddle Aeronautical University, USA

[2]h.song@ieee.org

[4]Institute for Communication Systems, University of Surrey, UK

[4]a.lei @surrey.ac.uk

1. Introduction

The introduction of Electric Vehicles (EV) will have a significant impact on the sustainable economic development of urban city. However, compared with traditional gasoline-powered vehicles, EVs currently have limited range, which necessitates regular recharging. Considering the limited charging infrastructure currently available in most countries, infrastructure investments and Renewable Energy Sources (RES) are critical. Thus, service quality provisioning is necessary for realizing EV market.

Unlike numerous previous works [1] which investigate "charging scheduling" (referred to when/whether to charge) for EVs already been parked at home/Charging Stations (CSs), a few works focus on "charging recommendation" (refer to where/which CS to charge) [2] for on-the-move EVs. The latter use case cannot be overlooked as it is the most important feature of EVs, especially for driving experience during journeys. On-the-move EVs will travel towards appropriate CSs for charging based on smart decision on where to charge, so as to experience a shorter waiting time for charging.

The effort towards sustainable engagement of EVs has not attracted enough attention from both industrial and academia communities. Even if there have been many 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 guarantee accurate information involved in decision making, how to optimally guide EV drivers towards charging place with the least waiting time, how to schedule charging services for EVs being parked within grid capacity.

Achieving this goal is of importance towards a positioning of efficient, scalable and smart ICT framework, makes it feasible to learn the whole picture of grid:

- Necessary information needs to be disseminated between stakeholders CSs and EVs, e.g., expected queuing time at individual CSs. In this context, how accurate CSs condition information plays an important role on the optimality of charging recommendation.
- Also, it is very time-consuming for the centralized Global Controller (GC) to achieve optimization, by seamlessly collecting data from all EVs and CSs, The complexity and computation load of this centralized solution, increases exponentially with the number of EVs.

This paper summaries the recent interdisciplinary research works on EV charging recommendation along with novel ICT frameworks, with an original taxonomy on how Intelligent Transportation Systems (ITS) technologies support the EV charging use case. Future directions are also highlighted to promote the future research.

2. Background

2.1 EV Charging Recommendation

As reviewed by the most recent survey [2], fruitful literature works have addressed "charging scheduling" [1], 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 communities thanks to the popularity of EVs. The works in [3][4][5] estimate the queuing time at CSs, such that the one with the minimum queueing time is ranked as the best charging option. The work in [3] compares the schemes to select CS based on either the closest distance or minimum waiting time, where results show that the latter performs better given high EVs density under city scenario. In [4], the CS with a higher capability to accept charging requests from on-the-move EVs, will propose this service with a higher frequency, while EVs sense this service with a decreasing function of their current battery levels. The CS-selection scheme in [5] adopts a pricing strategy to minimize congestion and maximize profit, by adapting the price depending on the number of EVs charging at each time point.

Further to above works solely consider local status of CSs, reservation-enabled schemes bring anticipated EVs mobility information (the charging reservation includes arrival time at recommended CS, and expected charging time spent there), in order to estimate whether a CS will be overloaded in a near future. The work in [6] 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 under the plug-in charging service [7][8][9][10][11][12] focus on city scenario, where the EV just heads to a single geographically distributed CS for charging. Here, the expected waiting time for charging is associated to that certain CS.

2.2 Urban Data for EV Charging Recommendation

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

The prevalence and accessibility of big data are changing the way people see their cities. Dedicated authorities should carefully consider which indicators were meaningful or how they should be analyzed. Here, the charging recommendation certainly benefits, via analytics of data from CSs and EVs (that ideally should be captured ubiquitously and timely):

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

2.3 Communication Technologies in ITS

ITS applications make use of wireless communications, including communications between vehicles, and between vehicles and fixed roadside installations, normally with single-hops or multiple hops between the source and destination. Today's vehicles are no longer stand-alone transportation means, due to the advancements on Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications enabled to access the Internet via recent technologies in mobile communications including WiFi, Bluetooth, 4G, and even 5G networks. The connected vehicles were aimed towards sustainable developments in transportation by enhancing safety and efficiency. Apart from the synchronous point-to-point communication, the topic based asynchronous communication pattern publish/subscribe (P/S) [13] has also been investigated.

2.4 Scalability of Charging System

The decision making on charging recommendation can be operated in various ways:

- The centralized manner relies on the cloud server GC to advance the resource efficiency, by taking the advantage of potential economies of scale. This brings much privacy concern, as EV status (e.g., location and trip destination) included in charging request will be released to the GC.
- The decentralized manner benefits to improved privacy protection, where the charging recommendation is executed by the EV individually. It is an attempt to betterment the speed and flexibility by reorganizing the locations of users, so as to enable control and execution of a service in the local.
- Further to above two standalone systems, the computation capability run by distributed decision makers maybe insufficient. Instead, a hybrid way is desirable to enhance the computation robustness, by removing the computational extensive tasks to GC, while the network edge entities which are closer to EVs process light-weight information aggregation and mining tasks.

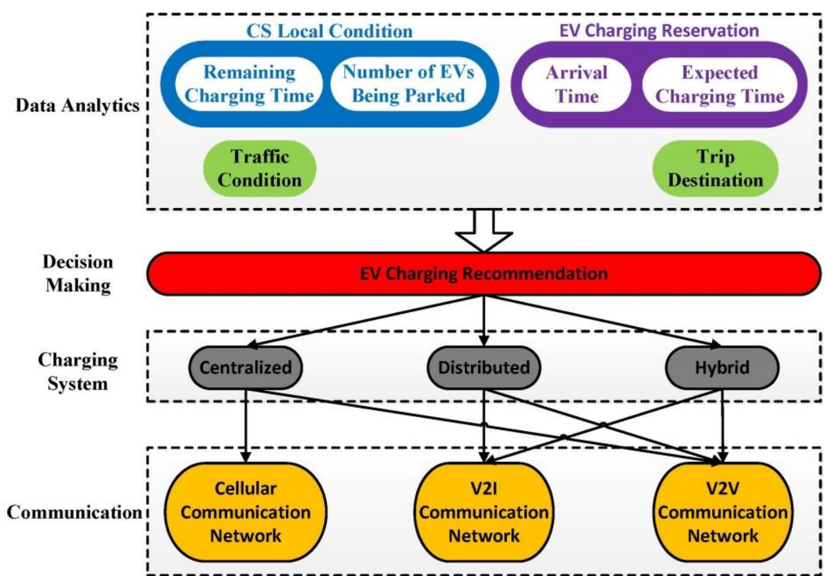


Fig. 1 A Taxonomy on Enabling ICT Technologies for EV Charging Recommendation

3. Recent Advances on ICT Enabled EV Charging Recommendation

Fig. 1 introduces a systematic picture from aspects of application driven data analytics for charging recommendation, to ICT enabling technologies supported charging systems.

3.1 Centralized Charging System

3.1.1 Cellular Network Communication Enabled

Here, the GC can access the real-time condition of CSs under its control, through reliable channel including wired-line or wireless communications, e.g., LTE or even 5G. Here, the interaction between EVs, and GC is considered as ubiquitous and free of delay, in order to enable a seamless control (as shown in Steps 1&2 in Fig. 2). [7] proposes a reservation based EV charging scheme, with the feature of periodically updating the charging reservation. By taking the road traffic jam into account, the variation of EV moving speed will affect its charging reservation (the arrival time at the CS, as well as the electricity consumption for travelling towards that CS). If without reservation updating, the EV may not reach a CS at the time it previously reserved, whereas the GC still has an obsolete knowledge that EV will reach on time. As such, the estimation on how long an incoming EV will wait for charging, is affected by the accuracy of the reservation information due to such uncertainty.

3.1.2 Enabling Internet of EVs for Charging Reservations Relay

It is worth noting that reporting EVs' charging reservations (deemed as an auxiliary service), is delay-tolerant (as the essential charging recommendation system still works, even if without reservation) and independent of charging request/reply. The cellular network is normally applied thanks to ubiquitous communication. However, such ubiquitous communication is costly and does not need to be anywhere and anytime, since the charging reservation is only generated when EVs have intentions on where to charge.

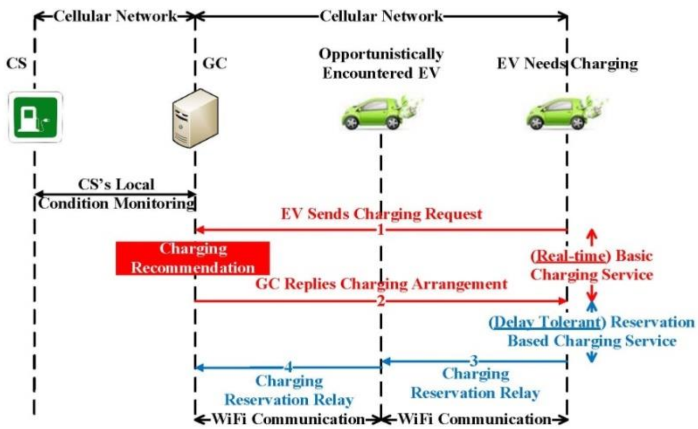


Fig. 2 Signaling Flow of V2V Relaying Charging Reservation

Alternatively, the V2V communication is receiving increasing interest, thanks to the inexpensive wireless connections and flexibility of installation on vehicles. Most of the problems in Vehicular Ad hoc NETworks (VANETs) arise from highly dynamic network topology, which results in the communication disruption along an end-to-end path towards destination. Here, the Delay/Disruption Tolerant Networking (DTN) [14] based routing protocols provide a significant advantage, by relying more on opportunistic communication to relay EVs' charging reservations.

Envisioning for Internet of EVs, [12] studies the feasibility to take the advantage of opportunistic V2V communication for delivery of EVs' charging reservations, in a multi-hop way (shown as Step 3&4 in Fig. 2), rather than the cellular network communication (if instead applied in Step 3). Thereby, the communication cost when using the V2V communication depends on the number of EVs, whereas the delivery overhead when using the cellular network communication depends on the number of charging reservations. In other words, the former is affected by the EVs density, whereas the latter is affected by the number of service requests. The study shows a great reduction of communication cost (in terms of charging reservation delivery) particularly given high EVs density.

3.2 Distributed Charging System

3.2.1 V2I Communication Network Enabled System

In spite that many literature works have adopted cellular network, the application of ITS is also of importance. For example, strategically deployed Road Side Units (RSUs) can support information dissemination as used by EV charging recommendation via V2I communication.

In order to enable the distributed charging system, in [8] the RSU is introduced to behave as an intermediate entity, for bridging the information flow exchange between EVs and the grid infrastructure CSs, through wireless communications. It is worth mentioning that different types of realization of RSUs (in particular the radio transmission coverage) affect the actual charging information, due to the information freshness related to the data exchange between EVs and the grid.

Besides, the P/S communication pattern is applied by decoupling the end-to-end connections between CSs and EVs. As a result, the system is featured with scalability (i.e., the number of connections in CS sides does not depend on the number of EVs) and efficiency (i.e., fast connection establishment and reduced bandwidth usage). By manipulating the topic, the battery switch based charging recommendation [15] for fast electric taxi charging is shown in Fig. 3.

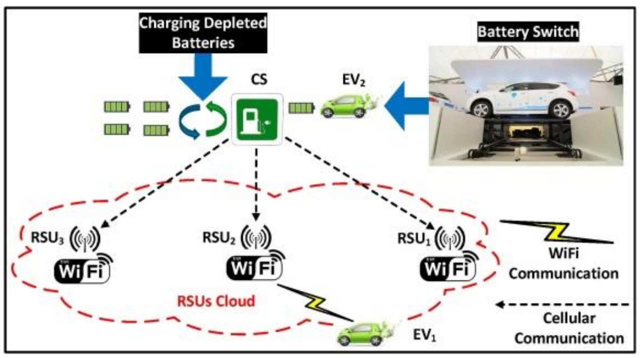


Fig. 3 V2I Enabled Communication Network for Battery Switch

3.2.2 V2V Communication Network Enabled System

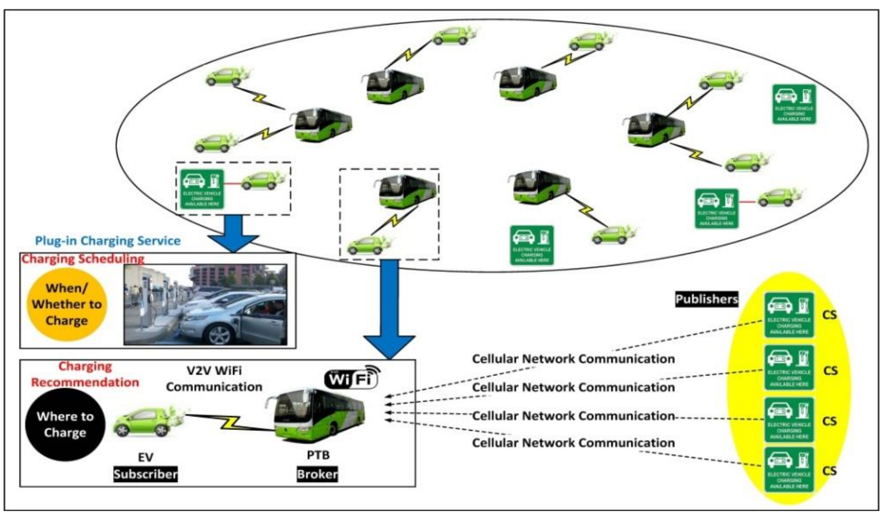


Fig. 4 V2V Enabled Communication Network for Distributed Charging System

In the context of new communication technologies especially for smart transportation and autonomous cars, new mechanisms have been proposed in connected vehicle environments, including V2I and V2V communications. On one hand, V2I based approaches require costs to deploy and maintain dedicated stationary infrastructures, and often they suffer from rigidness due to the lack of flexibility of deploying and possibly relocating fixed RSU facilities. In comparison, the V2V communication option proposed in [9] is a more flexible and efficient alternative, which supports necessary data dissemination between connected EVs and Public Transportation Buses (PTBs). The main benefit comes from the mobility-aware information dissemination for flexibility, as compared to the V2I communication networks.

3.3. Hybrid Charging System

3.3.1. V2I Communication Network Enabled Charging System

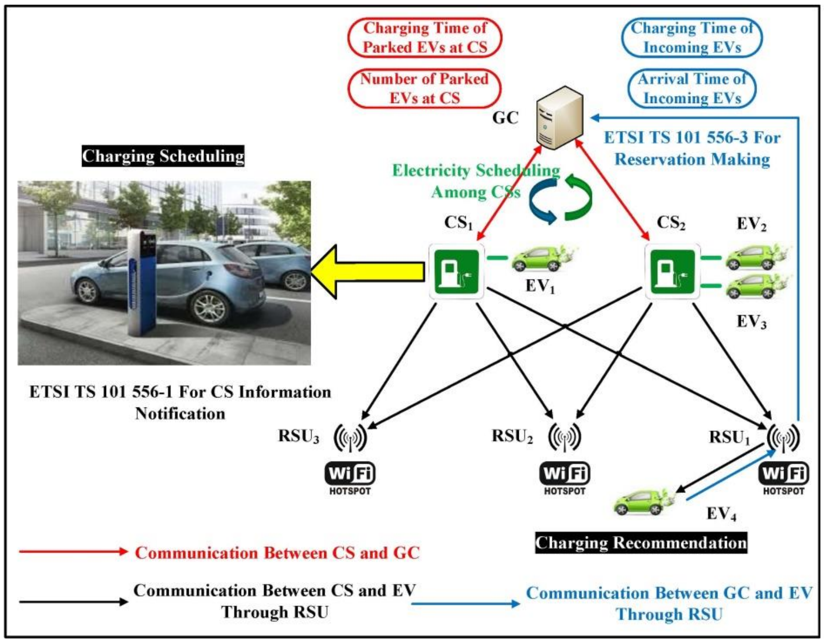


Fig. 5 V2I Enabled Communication Network for Hybrid Charging System

In [10], a hybrid charging system is designed based on V2I communication network, it realizes the application of "ETSI TS 101 556-1" [16] and "ETSI TS 101 556-3" [17] standards defined for EV charging recommendation. All CSs periodically publishes their charging points availability (predicted in a near future by the GC) to the RSUs. Furthermore, EVs are capable of making remote reservations to the GC through RSUs, before reaching their selected CSs. The GC then analyzes the EVs' charging reservations together with their associated CS's local condition information, to compute and notify the charging points availability publication of that CS. The GC also schedules the amount of electricity among CSs, depending on the anticipated charging demands (identified from received EVs' charging reservations).

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

3.3.2. V2X Communication Network Enabled Charging System

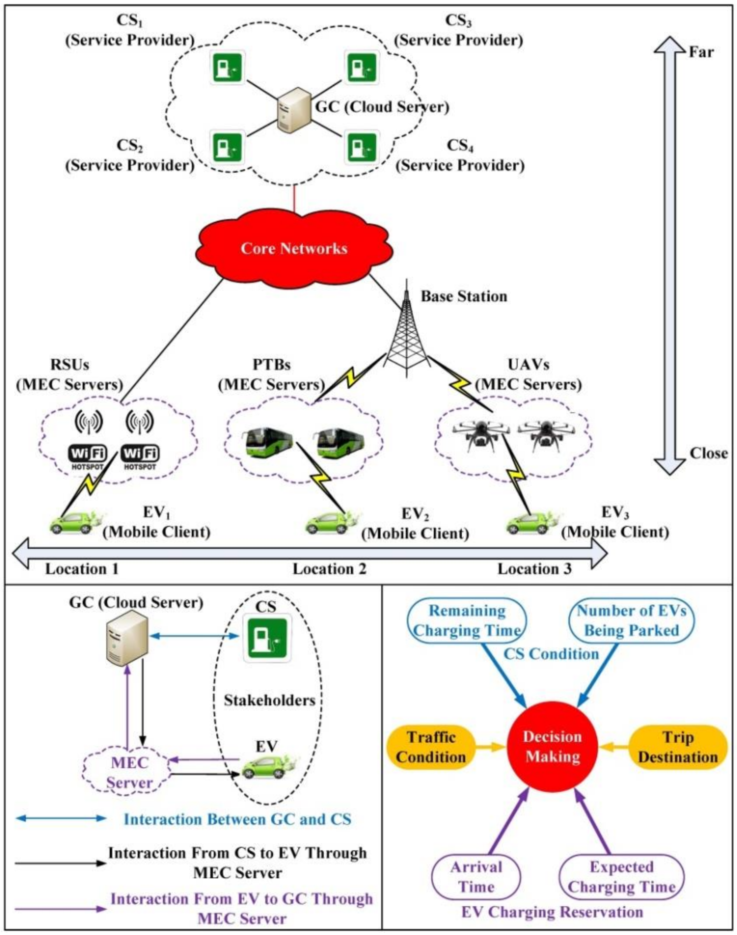


Fig. 6 V2X Enabled Communication Network for Hybrid Charging System

The rapid growth of Internet of Vehicles (IoV) with inter-vehicle devices demand, have placed severe demands on cloud infrastructure, which has led to moving computing and data services towards the edge of cloud, resulting in a novel Mobile Edge Computing (MEC) [18] architecture. MEC could reduce data transfer times, remove potential performance bottlenecks, and increase data security and enhance privacy while enabling advanced applications such as smart functioned infrastructure.

The cloud server locates in a centralized place, behaves as a centralized global manager to compute tasks (with information collected ubiquitously). MEC servers at different locations are owned and managed by separate operators and owners. With the collaboration among different operators, they can form a collaborative and decentralized computing system in the wide region. The work in [16] further extends the hybrid charging system with V2X communication network, by enabling RSUs, PTBs and Unmanned Aerial Vehicles (UAVs) as MEC servers to cooperate with GC. The integration of heterogeneous communication infrastructures enhances the computation towards ubiquitous (benefited from mobility and deployment of MEC servers), scalable (benefited from cloud/edge framework) ways.

4. Future Directions

4.1. Energy Integration and Sustainability

The wide spread of EVs experienced in recent years, must be accompanied by sufficient grid infrastructure deployment. The mismatch between EVs and infrastructures would potentially hinder the deployment rate of EVs. 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 RES provides a more straightforward approach to cope with the potential network issues as mentioned above. For example, the generation profile from photovoltaic coincides with the usage pattern and therefore charging profile of public charging stations, thus allowing a sustainable way of EV charging.

Besides, the engagement of Vehicle-to-Grid (V2G) lets charging points to be adapted to have the capability for bidirectional power flow, when certain operating conditions are satisfied. Therefore, with appropriate control and communication with the grid, EVs could be designed to operate as part of a "grid" helping to provide supply/demand matching for energy sustainability.

4.2. Data Analytics

The sustainability of EVs requires a fundamental study on data analytics on how/whether/which drivers are desirable to switch from diesel&petrol vehicles to EVs. This will thereby require the human centric data related to their routine, finance to predict and educate driver for switch benefit. Also, the driving pattern of EVs will be important to guide with cost efficient deployment of charging infrastructures.

4.3. Security and Privacy

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 including the pseudonym changing algorithms and pseudonym reuse schemes, both are required to be implemented in efficient and scalable manners. The future challenges are considered based on the nature of large number of connected EVs, high mobility, wide coverage area, heterogeneous communication systems. Specifically speaking, the future security and privacy schemes will have the abilities of little bandwidth resources consumption, large number node supportable and short processing time.

5. Conclusion

This paper introduced a number of recent advances jointly studying the ICT with EV charging recommendation (focuses on transportation aspect to minimize the charging waiting time). The centralized, distributed and hybrid systems in line with cellular network, V2I&V2V communication networks have been presented. The centralized charging system relies on GC to handle charging request from EVs with charging intention, and to make decision on which CS should plan for charging. In distributed charging system, EVs make their individual decisions for charging recommendation, where the RSUs and PTBs are applied to bridge the information published from CS to EVs. The hybrid charging system facilitates the computation advance of GC to predict and control the information dissemination in the network, and leaves the light-weight computation at network edge for information caching and mining to help EV for charging recommendation. Future challenges and directions are also highlighted to guide with the sustainability of research.

Acknowledgement

This work is supported in part by EU – Interreg North Sea Region programme - Smart, clean Energy and Electric Vehicles for the City (SEEV4-City) project.

References

[1] 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.

[2] E. S. Rigas, S. D. 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, Aug 2015.

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

[4] F. Hausler, E. Crisostomi, A. Schlote, I. Radusch, and R. Shorten, "Stochastic Park-and-Charge Balancing for Fully Electric and Plugin Hybrid Vehicles," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 2, pp. 895–901, April, 2014.

[5] E. Rigas, S. Ramchurn, N. Bassiliades, and G. Koutitas, "Congestion Management for Urban EV Charging Systems," in *IEEE SmartGrid-Comm '13*, Vancouver, Canada, October, 2013.

[6] 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.

[7] 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. PP, no. 99, pp. 1–12, 2016.

[8] Y. Cao, Ning Wang, George Kamel, Young-Jin Kim. "An Electric Vehicle Charging Management Scheme Based on Publish/Subscribe Communication Framework". IEEE Systems Journal, vol. 11, no. 3, pp. 1822 - 1835, September, 2017.

[9] Y. Cao and N. Wang, "Towards Efficient Electric Vehicle Charging Using VANET-Based Information Dissemination," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 4, pp. 2886–2901, April 2017.

[10] Yue Cao, Omprakash Kaiwartya, Ran Wang, Tao Jiang, Yang Cao, Nauman Aslam and Graham Sexton. "Towards Efficient, Scalable and Coordinated EV Charging Management". IEEE Wireless Communications, vol. 24, no. 2, pp. 66-73, April, 2017.

[11] Y. Cao, Houbing Song, Omprakash Kaiwartya, Bingpeng Zhou, Yuan Zhuang, Yang Cao and Xu Zhang. "Mobile Edge Computing for Big Data-Enabled Electric Vehicle Charging". IEEE Communications Magazine. (To appear in 2017)

[12] Y. Cao, Xu Zhang, Ran Wang, Linyu Peng, Nauman Aslam and Xiaomin Chen. "Applying DTN Routing for Reservation-Driven EV Charging Management in Smart Cities". IEEE IWCMC, Valencia, Spain, 2017.

[13] P. T. Eugster, P. A. Felber, R. Guerraoui, and A.-M. Kermarrec, "The Many Faces of Publish/Subscribe," ACM Computing Surveys, vol. 35, no. 2, pp. 114–131, June, 2003.

[14] 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.

[15] Y. Cao, Shusen Yang, Geyong Min, Xing Zhang, Houbing Song, Omprakash Kaiwartya and Nauman Aslam. "A Cost-Efficient Communication Framework or Battery Switch Based Electric Vehicle Charging". IEEE Communications Magazine, vol. 5, no. 5, pp. 162-169, May, 2017.

[16] "ETSI TS 101 556-1 v1.1.1 Intelligent Transport Systems (ITS); Infrastructure to Vehicle Communication; Part 1: Electric Vehicle Charging Spot Notification Specification," Tech. Rep.

[17] "ETSI TS 101 556-3 v1.1.1 Intelligent Transport Systems (ITS); Infrastructure to Vehicle Communications; Part 3: Communications System for the Planning and Reservation of EV Energy Supply Using Wireless Networks," Tech. Rep.

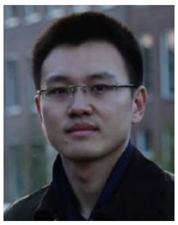
[18] M. T. Beck, M. Werner, S. Feld, and S. Schimper, "Mobile edge computing: A taxonomy," in *Proc. of the Sixth International Conference on Advances in Future Internet*. Citeseer, 2014.

[19] Y. Zhou, N. Cheng, N. Lu, and X. S. Shen, "Multi-UAV-Aided Networks: Aerial-Ground Cooperative Vehicular Networking Architecture," IEEE Vehicular Technology Magazine, vol. 10, no. 4, pp. 36–44, December 2015.

Yue Cao received his PhD degree from the Institute for Communication Systems (ICS) formerly known as Centre for Communication Systems Research, at University of Surrey, Guildford, UK in 2013 and further as Research Fellow. Since August 2017, he has been the Senior Lecturer (previously was Lecturer since October 2016) in Department of Computer and Information Sciences, at Northumbria University, Newcastle upon Tyne, UK. His research interests focus on Delay/Disruption Tolerant Networks, E-Mobility, Autonomous Valet Parking, QoS/QoE in 5G.

Houbing Song received the Ph.D. degree in electrical engineering from the University of Virginia, Charlottesville, VA, in August 2012. In August 2017, he joined the Department of Electrical, Computer, Software, and Systems Engineering, Embry-Riddle Aeronautical University, Daytona Beach, FL, where he is currently an Assistant Professor and the Director of the Security and Optimization for Networked Globe Laboratory (SONG Lab, www.SONGLab.us). He serves as an Associate Technical Editor for IEEE Communications Magazine.

Omprakash Kaiwartya received his PhD degree from the School of Computer and Systems Sciences (SC&SS), at the Jawaharlal Nehru University (JNU), New Delhi, India in 2015. He is currently a Postdoctoral Research Fellow at the Faculty of Computing, Universiti Teknologi Malaysia (UTM). His research interests focus on Internet of Vehicles (IoV), Electronic Vehicles (EV), Vehicular Ad-hoc Networks (VANETs), and Wireless Sensor Networks (WSNs). He has been involved in funded projects related to communication protocols for VANETs and WSNs, as key researcher for UTM and JNU.



Ao Lei received his BEng degree in communication engineering at Harbin Institute of Technology, China and University of Birmingham, UK, in 2013, and the MSc degree in communication engineering at the University of York, UK, in 2014. He is a PhD candidate in communication engineering in the Institute of Communication Systems at the University of Surrey, UK. His research interests include security and privacy for vehicular networks and privacy protection for location based services. He is currently involved with two EU-funded Projects on security and privacy (PETRAS and B-IoT).

Yue Wang received the B.Eng degree and Ph.D. degree in electronic and electrical engineering from University of Strathclyde, Glasgow, Scotland, in 2010 and 2014, respectively. She is currently working as a research fellow in Northumbria University, in Newcastle upon Tyne, UK. Her research interests include smart integration of electric vehicles and renewable energy into power systems and wind turbine condition monitoring.

Ghanim Putrus leads the Power and Wind Energy Research group at the Faculty of Engineering and Environment, Northumbria University. He is Associate Editor for Elsevier Renewable Energy journal and serves on the technical/steering committees for several conferences. He is involved in the Institution of Engineering Technology (IET) professional activities and served on the executive committee of the IET Power Trading and Control Professional Network (2001-2009). His main research interests are the application of power electronics in power systems, power quality, integration of renewable energy resources and electric vehicles into power distribution networks.