MULTIMEDIA COMMUNICATIONS TECHNICAL COMMITTEE
http://www.comsoc.org/~mmc

MMTC Communications - Frontiers

Vol. 12, No. 6, November 2017

CONTENTS

Message from the MMTC Chair

Dear MMTC colleagues and friends,

I hope this message finds you well! I would like to take this opportunity to invite all of you to the next MMTC meeting at IEEE GLOBECOM 2017 in Singapore. We will meet old and new friends, and review the MMTC activities with updates from the officers, boards, and IGs, as well as updates of MMTC sponsored conferences/workshops at these meetings. We will also discuss potential problems and challenges, as well as any issues that are raised at the meeting.

The MMTC meeting at IEEE GLOBECOM 2017 in Singapore
When: 12:00-14:00, Wednesday, Dec. 6, 2017
Where: Room 4913, Marina Bay Sands Singapore,10 Bayfront Avenue, Singapore 018956

In addition, we will recognize two MMTC Communications Board members with the *2017 MMTC Best Editor Awards* for their excellent service on the MMTC Communications-Frontiers and MMTC Communications-Reviews boards, respectively. The 2017 Best Editor Award winners are:

Dr. Melike Erol-Kantarci
University of Ottawa, Ottawa, Canada
Citation: For outstanding service on the Frontiers Board

Dr. Roger Zimmermann
National University of Singapore, Singapore
Citation: For outstanding service on the Review Board

Big congratulations to Melike and Roger! The MMTC Communications are critical elements of the MMTC. Several other TCs have started or plan to start similar publications as motived by the success of MMTC Communications. I would like to thank our Vice Chair-Letters & Member Communications, Dr. Honggang Wang, and the Frontiers and Reviews Boards for their hard work and excellent contributions to the MMTC!

MMTC has a long history of close collaboration with key multimedia journals and magazines, such as IEEE Transactions on Multimedia (TMM), IEEE Transactions on Circuit and Systems for Video Technology (T-CSVT), and IEEE Multimedia (MM). Earlier this year, we nominated three candidates, through a rigorous voting procedure, for Associate Editor (AE) of TMM. Two of them, Dr. Chuan Wu (The University of Hong Kong, Hong Kong) and Dr. Sanjeev Mehrotra (Microsoft AI & Research, USA) have been appointed as TMM AE by the Editor-in-Chief Dr. Wenwu Zhu. In addition, Dr. Huadong Ma (Beijing University of Posts and Telecommunications, China), a long time active member of MMTC, has also been appointed as TMM AE (nominated by another TC). Congratulations to Chuan, Sanjeev and Huadong!

As nominated by the MMTC, Drs. Xiaoqing Zhu (Cisco Systems Inc.), Mahbub Hassan (University of New South Wales), Hermann Hellwagner (Alpen-Adria-Universitaet Klagenfurt), and myself has guest edited a TMM Special Issue on “Video Over Future Networks.” We received a total of forty-one submissions, and sixteen of them were accepted after two rounds of rigorous reviews. This special issue has been published in the October 2017 issue of TMM. In addition, MMTC nominated two special issue proposals to TMM, and the TMM editorial board has approved the following special issue. Please consider submitting your latest work to this special issue.

IEEE TMM Special Issue on “Trustworthiness in Social Multimedia Analytics and Delivery: Models, Technologies, Privacy, and Applications”
Guest Editors: Profs. Zhou Su (Shanghai University, Shanghai, China), Qing Fang (Yamagata University, Yamagata, Japan), Honggang Wang (UMass Dartmouth, Dartmouth, MA, USA), Sanjeev Mehrotra (Microsoft, USA), Ali C. Begen (Ozyegin University, Istanbul, Turkey), Qiang (Chan) Ye (University of Prince Edward Island Charlottetown, PE, Canada), and Andrea Cavallaro (Queen Mary University of London, UK)
Manuscript Due: July 1st, 2018

IEEE COMSOC MMTC Communications - Frontiers

Recently, the incoming Editor-in-Chief of T-CSVT, Dr. Shipeng Li, has requested nominations/self-nominations from our TC for AE of T-CSVT, which shares great interests with the MMTC. Dr. Li also requests special issue proposals for T-CSVT from the MMTC community. The detailed call and nomination form have been distributed through the MMTC mailing list. Please check it out if you are interested.

We also nominated four active MMTC members to the ComSoc Distinguished Lecturer Program. We will hear about the decisions from the Distinguished Lecturers Selection Committee at GLOBECOM 2017 shortly.

I would like to take this opportunity to encourage you to get more involved in the MMTC activities. The current leadership team's term will end by May 2018. A call for nominations for MMTC officers will be sent out in Spring 2018 and the new officers for the next term will be voted at the MMTC meeting at IEEE ICC 2018, May 20-24, 2018, in Kansas City, MO, USA. Please consider nominating a qualified colleague or submitting a self-nomination if you are interested.

Check out the many resources and opportunities MMTC offers to its members at the MMTC website http://mmc.committees.comsoc.org, for MMTC sponsored journals, conferences/workshops, MMTC Communications—Frontiers and Reviews, and MMTC Interest Groups. Every year, MMTC recommends associate editors and special issue proposals to sponsored journals (e.g., IEEE Transactions on Multimedia) and TPC or Track Co-Chairs to sponsored conferences (e.g., IEEE ICC, IEEE GLBOECOM, IEEE ICME, IEEE CCNC, etc.). MMTC also helps its members for elevation to senior member or Fellow of the IEEE, and nominates Distinguished Lectures to ComSoc. In addition, MMTC recognizes its members with the Best Journal and Conference Paper Awards, Distinguished Service Award, Outstanding Leadership Award, and Excellent Editor Awards every year. Please stay tuned for announcements from the MMTC mailing list.

I thank the Frontier Board Members for their hard work and hope you enjoy reading this MMTC Communications—Frontiers issue. If you have any suggestions or comments, please do not hesitate to contact me.

Sincerely,

Shiwen Mao
Chair, Multimedia Communications Technical Committee
IEEE Communications Society

SPECIAL ISSUE ON Data Analytics for Smart Grid and Electric Vehicles

Guest Editor: Melike Erol-Kantarci, University of Ottawa, Canada

{melike.erolkantarci}@uottawa.ca

Data analytics recently started to play a significant role in large complex systems that generate vast amount data which is referred to as big data. Today, big data can come from a variety of devices, vehicles, buildings, power grid equipment, and Internet of Things (IoT). Smart grid and Electric Vehicles (EVs) are among the largest producers and consumers of big data. There is a close relationship between electric vehicle and smart grid since the charging behavior of EVs unavoidably influences the grid. Especially the charging station plays an important role between electric vehicle and smart grid. Besides the big data generated by these integrated systems, as consumers of the data, smart grid and EVs can benefit significantly from data analytics in decision making.

The five papers included in this special issue on "Data Analytics for Smart Grid and Electric Vehicles" brings a collection of points of views of globally recognized researchers in this field and provides the readers cutting-edge results from their groups. The included papers are briefly introduced below.

In "Interconnection of Smart Grid and Electric Vehicles with a Charging System," authored by G. Habault, G. Le Gall, G. Z. Papadopoulos, N. Montavont and P. Chatzimisios, the authors present solutions to provide efficient tools for combining monitoring information towards charging EVs. The authors aim to provide a smart charging service that help the driver to control the EV charging process based on information retrieved from several sources including the smart grid (e.g. pricing information, incentives), the user (e.g., preferences of the driver) and the availability of local generation. The presented tools allow the smart grid to control its network by providing pricing, incentives and information on its loads.

P. D. Diamantoulakis and G. K. Karagiannidis, in their paper titled "Big Data Analytics for Smart Grid Supervisory Control," emphasize the importance of Big Data Analytics to provide efficient solutions in specific problems related to data processing in the smart grid. The authors focus on supervisory control and intelligent real-time monitoring techniques that enable detecting abnormal events, finding their location and causes, and even predicting and eliminating faults before they happen. They also discuss big data analytics in demand side energy management and EV charging control, as well as discussing security and privacy aspect of the topic which has paramount importance.

The paper entitled, "A scalable and interoperable platform for transactional demand reduction," by J. Fattahi and H. Schriemer introduce a novel architecture that involves demand response through transactional balance between power demand and supply. Within the presented Grid Edge Active Transactional Demand Response (GREAT-DR) architecture, the authors propose to employ near real-time communication between a transformer-level demand controller and its network of home energy management systems. The aim is to maximize electricity demand reduction by optimally scheduling the operation of each home energy management system. The importance of data, its usage, as well as security and privacy concerns are all delicately treated by the authors.

In "Electric Vehicle Charging Recommendation and Enabling ICT Technologies: Recent Advances and Future Directions," by Y. Cao, H. Song, O. Kaiwartya, A. Lei, Y. Wang and G. Putrus, the authors summarize the recent interdisciplinary research works on EV charging recommendations concerning big data and provide an original taxonomy on how Intelligent Transportation Systems (ITS) technologies support the EV charging use case. They also discuss energy integration and sustainability as a future perspective to the topic.

The research in "Big Data for Electric Vehicle-Grid Integration (EVGI) Decision Making," by N. Singh, M. Kisacikoglu and M. Erol-Kantarci surveys the recent research efforts that make use of big data tools in the smart grid and EV domain. The authors first provide a classification of potential big data sources. They, then, introduce research studies that use tools such as Hadoop, NoSQL and Weka, in order to process big data arriving from EVs and transportation systems. The authors show how these data has been used in decision making such as siting of public charging stations.

The purpose of this special issue is to introduce several state-of-the-art research efforts in big data analytics in the smart grid and electric vehicle fields. The valuable contributions of the renowned researchers make the special issue an excellent collection for the readers. The guest editor is thankful for all the authors for their contributions and the help from the MMTC Communications – Frontiers Board.

Melike Erol-Kantarci is an assistant professor at the School of Electrical Engineering and Computer Science at the University of Ottawa, ON, Canada. She is the founding director of the Networked Systems and Communications Research (NETCORE) laboratory. She is also a courtesy assistant professor at the Department of Electrical and Computer Engineering at Clarkson University, Potsdam, NY, where she was an assistant professor prior to joining University of Ottawa. She received her Ph.D. and M.Sc. degrees in Computer Engineering from Istanbul Technical University in 2009 and 2004, respectively. During her Ph.D. studies, she was a Fulbright visiting researcher at the Computer Science Department of the University of California Los Angeles (UCLA). She is an editor of the IEEE Communications Letters and IEEE Access. She is the co-editor of the books "Transportation and Power Grid in Smart Cities: Communication Networks and Services" and "Smart Grid: Networking, Data Management, and Business Models". She is a senior member of the IEEE and the past vice-chair for Women in Engineering (WIE) at the IEEE Ottawa Section. She is currently the vice-chair of Green Smart Grid Communications special interest group of IEEE Technical Committee on Green Communications and Computing. She is also the research group leader for IEEE Smart Grid and Big Data Standardization. Her main research interests are 5G and beyond wireless networks, smart grid, cyber-physical systems, electric vehicles, Internet of Things, big data and wireless sensor networks.

Interconnection of Smart Grid and Electric Vehicles with a Charging System

Guillaume Habault[1], Guillaume Le Gall[1], Georgios Z. Papadopoulos[1],
Nicolas Montavont[1] and Periklis Chatzimisios[2]
[1] IMT Atlantique, IRISA, UBL, Rennes Campus, France
{guillaume.habault, guillaume. legall, georgios.papadopoulos,
nicolas.montavont}@imt-atlantique.fr
[2]CSSN Research Lab, Department of Informatics, Alexander TEI of Thessaloniki, Greece
pchatzimisios@ieee.org

1. Introduction

The electricity demand is expected to significantly increase in the coming years, and part of this increase is due to the emergence of Electric Vehicles (EVs). In the meanwhile, the power sector is undergoing important changes, mainly due to the switch from fossil to renewable energies, the evolving energy policies and the emergence of less-reliable renewable micro-generation [1]. Furthermore, the grid structure is evolving from a centralized architecture to a distributed one with individual premises equipped with local renewable production units [2]. In order to efficiently balance production and consumption, real-time measurements, predictions and control capabilities are required in a widespread management system. Therefore, it is of crucial importance to set systems capable of monitoring devices and analyzing corresponding data in order to properly manage electric consumption, production and storage in what is called the Smart Grid (SG). Such management can be performed at different levels of the distribution network from the user premises to any aggregating nodes of utilities.

The usage of EVs is steadily growing and progressively envisioned for the future, especially in order to reduce carbon footprint. So far, EVs and associated services have been deployed for fleet usage [3] and they are slowly appearing in home usage. However, EVs breakthrough has been delayed by the lack of charging stations within the transportation landscape and the number of concurrent standards. As a matter of fact, existing charging stations do not support all standards and this prevents EVs to be broadly deployed. Such charging stations must respond to multiple requirements in terms of power availability, location, charging mode, voltage output, vehicle compatibility and security at different levels [4]. As a result, some standardization efforts have to be made before dealing with the management of these charging stations. It is also worth mentioning that most of the charging stations that are currently deployed do not implement features related to the SG. Therefore, another challenge is to take into account energy availability, its cost and maintain battery performance while considering previously mentioned SG aspects. Therefore, some intelligence is required in order to properly use the available energy at a given time while considering battery constraints and cost. As a result, EV systems will benefit to be linked with SG systems in order for them to interact and determine optimal energy usage.

In addition, SG systems will also benefit from being able to monitor and possibly control charging periods of EVs. Currently, the drivers mostly charge their EV when they arrive at work or when they come back home after work. Therefore, EVs are mainly charge during peak hours. According to Peças Lopes et al. in [5] such behavior is not to be considered for utilities since it will load the network even more than it is already. On the contrary, utilities should be able to improve their distribution network load by being able to inform about optimal periods and, thus, postpone the charging process at a more convenient time. However, the tools necessary to reach such a goal are not available yet. When both systems will be connected, some multi-objectives charging strategies will be required in order for the whole system to function. Several challenges arise with these goals, such as how to automate charging processes while enabling systems to consider user needs, prices and electricity availability as well as renewable energy production, if any.

This article presents some solutions developed and studied in order to provide efficient tools for interconnecting different monitoring information towards a common goal: charging a private EV. We especially focus on the use case of charging private EVs, as it is the most emerging scenario to encourage deployment of EVs at home. The research carried out toward this use case enables them to provide a smart charging service that help the driver to control the EV charging process based on information retrieved from a) the SG (such as incentives); b) the user (needs for the EV); and c) the house (availability of local PhotoVoltaic (PV) production).

2. Architecture enabling efficient data analytics and advanced services

This article aims to study private EV usage based on the scenario illustrated in Figure 1. In this use case, a house is equipped with an Energy Management System (EMS), a private EV, PV production units and stationary batteries. Several Internet of Things (IoT) devices are monitoring electricity consumption, production and storage of the house and its appliances. The EMS is managing all the monitored data from the house and if applicable, control appliances. The power produced by PV panels is stored in the stationary batteries and is available for the house consumption such as domestic appliances or the EV. The stationary batteries may have different purposes. They could be used to reduce house electricity cost but also, on grid-demand such as during peak hours, to reduce the overall load of the grid (the house would then receive incentives for such behaviors). House residents can inform the EMS of their needs regarding the appliances and the EV (when they will use it and when it will be available for charging process). With these information the EMS can decide when it can switch ON or OFF appliances but also shift in time some tasks (e.g., washing machine) in order to optimize house electricity balance.

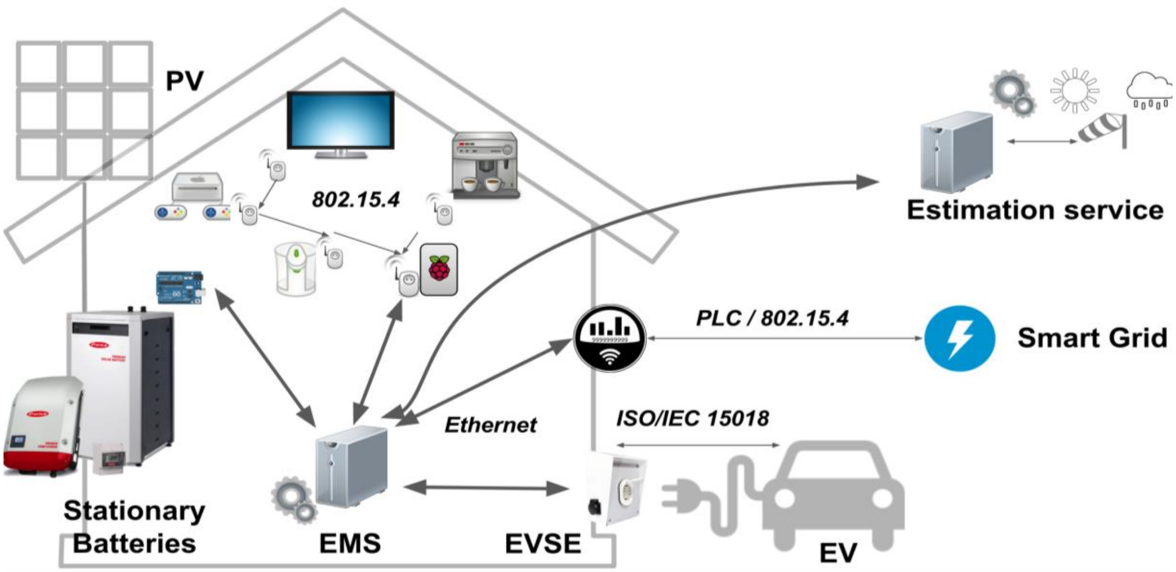


Fig. 1: Schematic view of the architecture scenario

The house also interacts with outside equipment in order to retrieve useful information for its local management. First, it can communicate with the electric grid via its smart meter. This actually enables the EMS to receive grid demands and pricing information. Then, as presented in [2], it also have access to a service that can estimate future renewable production based on house position, weather forecast and historical production measurements.

Based on the EV reservation scheduling, PV production estimation and grid-demand, the authors defined a smart charging system that computes the best periods to charge the EV while conforming to the EV battery constraints and user requests.

3. Data analytics and communication toward optimal interactions between Smart Grid and EVs

In order to properly plan EV charging, the house has to communicate with the grid using a SG architecture. This communication requires to be reliable for the house to always receive grid prices and demands. Research is conducted in order for the smart meter to have reliable communication using different technologies at the same time [6]. Based on these information, the EMS can determine electricity pricing profile as well as grid preferred periods.
All monitored measurements from the house are sent to the EMS to let it store data and analyze them. Smart plugs using IEEE 802.15.4 connectivity are used to monitor and efficiently transmit appliance consumption information (e.g., coffee machine, boiler). These data help the EMS to determine electricity requirements for the appliances

compared to the PV production as shown in Figure 2. The house electricity production is monitored and controlled by utilizing an Arduino device. In [7], a set of mechanisms using semantics has been defined and studied in order to limit the impact of monitoring traffic in the network while providing dynamic control of data granularity.

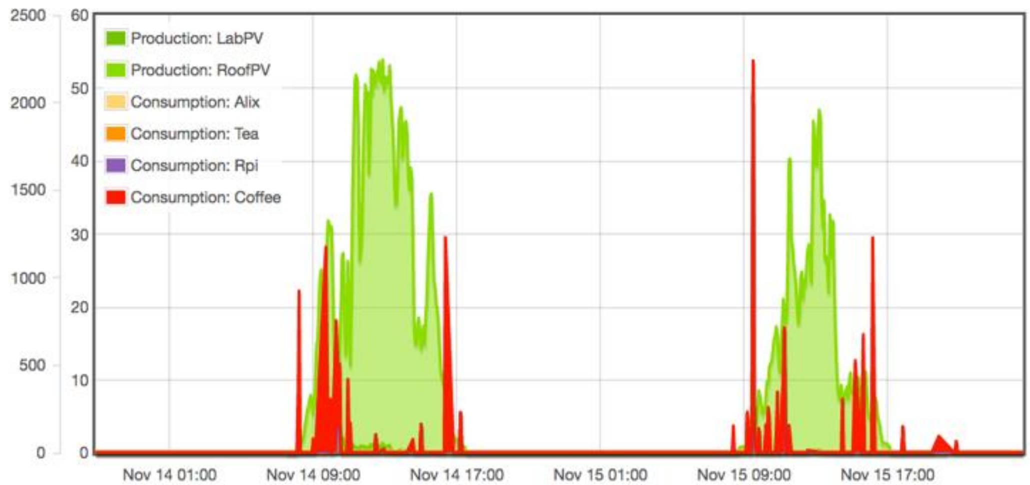


Fig. 2: Visualization of a building production (green) and consumption (other colors)

As previously mentioned, the production measurements are compared to the weather forecast by an external service in order to estimate future production. This results in providing to the EMS an estimation production profile, which helps the EMS determine how to use such a production. Depending on the stationary battery state of charge, the EMS can decide to store the production and/or use the production. Based on these decisions, it can provide to the EV Supply Equipment (EVSE) an updated profile of the production available for the EV.

The local charging station (EVSE) monitors the consumption of the EV and communicates with it via the protocol ISO/IEC 15118 [8]. This protocol allows the negotiation of a planned charging profile and provides several information such as when the EV is plugged into the charging system, the state of charge of the mobile battery as well as additional safety features (compared to basic charging).

A charging system was developed at IMT Atlantique that uses the profiles that were previously defined and the authors implemented the ISO/IEC 15118 protocol. This software enables a negotiation of a charging profile between an EV and the grid (via the EMS). At the end of the negotiation, as shown in Figure 3, an optimal charging profile is obtained, taking into consideration:

1. The constraints provided by the user, i.e., reservation scheduling, next departure (period of stay);
2. The grid electricity prices profile and the preferred period;
3. The stationary battery state of charge level profile as well as the production estimation profile.

Several charging strategies can be envisioned with such a charging system. For instance, it can target to lower electricity cost for EV charging, to maximize usage of renewable production to charge EV and much more.

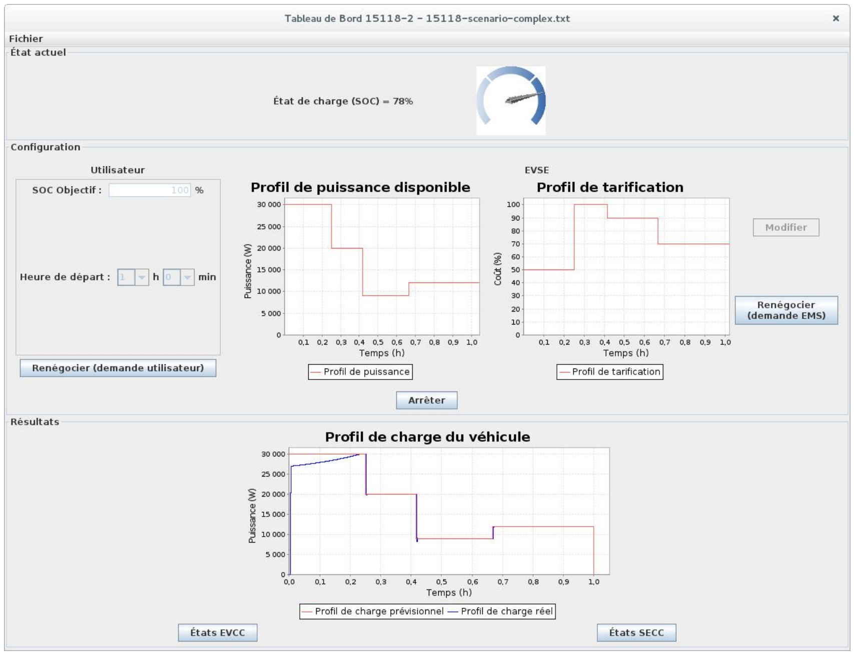


Fig. 3: Charging system dashboard - Illustrations of different profiles used to compute a charging profile and control the process

4. Conclusion

In this article, a possible interaction between a Smart Grid system and an Electric Vehicle charging system based on data monitoring was presented. The tools developed in the studied scenario provide different benefits and they allow the Smart Grid to control its network by providing pricing, incentives and information on its loads. At the same time, the decision of the charging period is up to the final user based on its preferred strategy. It is clear that this implementation could be used for other scenarios and it will greatly enhance the EV penetration in both domestic and business areas. This implementation could even go further. Firstly, the EV could be seen as a mobile battery and instead of only be charged, its remaining power could also be re-injected in the network. This scenario could participate in reducing the load on the distribution network at given moments. Secondly, the proposed system could be enhanced by taking into consideration the charging stages and Battery Management System balancing strategy into the planned charging profile computation.

References

[1] F. Lemercier, G. Habault, G. Z. Papadopoulos, P. Maille, P. Chatzimisios, and N. Montavont, “Communication architectures and technologies for advanced Smart Grid Services,” in Transportation and Power Grid in Smart Cities: Communication Networks and Services. UK: John Wiley, 2017.
[2] G. Habault, J. Hursti, and J. Bonnin, “Defining a Distributed Architecture for Smart Energy Aware Systems,” in Complex Systems Design & Management, 2016, ch. 8.
[3] M. Lefrancois, G. Habault, C. Ramondou, and E. Françon, “Outsourcing Electric Vehicle Smart Charging on the Web of Data”, IARA, The First International Conference on Green Communications, Computing and Technologies, 2016.
[4] S. Fries, Steffen, and R. Falk, “Securely connecting Electric Vehicles to the Smart Grid”, International Journal of Advances in Internet Technology, 2013.
[5] J. A. Peças Lopes, F. J. Soares, P. M. Almeida, M. Moreira da Silva, “Smart Charging Strategies for Electric Vehicles: Enhancing Grid Performance and Maximizing the Use of Variable Renewable Energy Resources”, EVS24, Norway, 2009.
[6] F. Lemercier, N. Montavont, L. Toutain, K. Vijayasankar, R. Vedantham, and P. Chiummiento, “Support for hybrid network in RPL”, in Proc. of the IEEE SmartGridComm, 2016, pp. 527–532.
[7] G. Habault, M. Lefrançois, F. Lemercier, N. Montavont, P. Chatzimisios and G. Z. Papadopoulos, “Monitoring Traffic Optimization in Smart Grid”, in *IEEE Transactions on Industrial Informatics*, vol. PP, no. 99, pp. 1-1.
[8] J. Schmutzler, C. Wietfeld and C. A. Andersen, “Distributed energy resource management for electric vehicles using IEC 61850 and ISO/IEC 15118”, *2012 IEEE Vehicle Power and Propulsion Conference*, Seoul, 2012, pp. 1457-1462.

Guillaume Habault received both the M.Sc. degree in networks and software systems in 2009 and the Ph.D. degree in computer

science and telecommunications in 2015 from IMT Atlantique (formerly Télécom Bretagne), Rennes, France.
Currently, he works as a Post-doctorate for Institut Mines Télécom. He particularly participated in designing, testing and implementing an Internet of Things architecture for the European project Smart Energy Aware Systems (SEAS). His current research interests include, but are not limited to, management and coordination of distributed micro-generation sources in Smart Grid. Such objectives require innovative communication solutions in order to have real-time and dynamic control and monitoring of energy loads.

Guillaume Le Gall is a Research Engineer at IMT Atlantique, Rennes, France. He received a Masters degree in 2013 from IMT Atlantique (formerly Mine de Nantes), in Automatics and Computer Science.
In recent years, he has been working on communications for Intelligent Transport Systems (ITS) in general, and especially electric vehicles. The research he is involved in focuses mainly on on-board vehicle communications, Vehicle to Grid, and Vehicle to Vehicle communications. He participated in several national projects about Smart Charging of EVs (Greenfeed, Eguise), and was one of the core developers for the IMT Atlantique's implementation of the ISO/IEC 15118 standard.

Georgios Z. Papadopoulos serves as an Associate Professor at the IMT Atlantique in Rennes, France. Previously, he was a Postdoctoral Researcher at the University of Bristol. He received his Ph.D. from University of Strasbourg, in 2015 with honors, his M.Sc. in Telematics Engineering from University Carlos III of Madrid in 2012 and his B.Sc. in Informatics from Alexander T.E.I. of Thessaloniki in 2011.
Dr. Papadopoulos has participated in various international and national (FP7 RERUM, FIT Equipex) research projects. Moreover, he has received the prestigious French national ANR JCJC grant for young researchers. He has been involved in the organization of many international events (AdHoc-Now'18, IEEE ISCC'17). His research interests include Industrial IoT, LPWAN and Smart Grid.
Dr. Papadopoulos has received the Best Ph.D. Thesis Award granted by the University of Strasbourg and he was a recipient of two Best Paper Awards (IFIP Med-Hoc-Net 2014 and IEEE SENSORS 2014).

Nicolas Montavont is a full Professor at IMT Atlantique, Head of the IRISA team called OCIF (Communicating objects and Internet of the Future). He obtained his M.Sc. and PhD degrees in Computer science from the University of Strasbourg, France, in 2001 and 2004 respectively. He did a postdoc at National institute of Standard and Technologies (NIST) in Gaithersburg, USA. His research topics during these first years of research were mobility and multihoming management in IPv6 networks. He chaired the Mobile Node with Multiple Interfaces (Monami6) working group at the IETF from 2005 a 2007 and contributed to several standards, with a strong experience in horizontal and vertical handovers.
Pr. Montavont participated to several national (Cyberté, Remora) projects, as well as European projects (Anemone, Sail). From 2007, he chaired an internal working group at IMT Atlantique to work on energy efficiency in communication networks. His research topics evolve toward Internet of Things, smart grids and green communication infrastructure and protocols. His is currently involved in developing Information systems for industrial network and energy monitoring.

Periklis Chatzimisios serves as an Associate Professor, the Director of the Computing Systems, Security and Networks (CSSN) Research Lab and a Division Head for the Department of Informatics at the Alexander TEI of Thessaloniki (ATEITHE), Greece.
He is involved in several standardization serving as Member of the IEEE Communication Society (ComSoc) Standards Program Development Board and the IEEE ComSoc Standards Development Board. He is the editor/author of 8 books and more than 120 peer-reviewed papers and book chapters on the topics of performance evaluation and standardization activities of mobile/wireless communications, Internet of Things, Big Data and vehicular networking. His published research work has received more than 2500 citations by other researchers. Dr. Chatzimisios obtained his Ph.D. from Bournemouth University (UK) in 2005 and his B.Sc. from ATEITHE in 2000.

Big Data Analytics for Smart Grid Supervisory Control

Panagiotis D. Diamantoulakis and George K. Karagiannidis
Aristotle University of Thessaloniki, Thessaloniki 54124, Greece
{padiaman, geokarag}@auth.gr

1. Introduction

The development of new applications and requirements, such as the integration of millions of alternative distributed systems, the electric vehicles, the two-way flow of power, etc., places tremendous pressure on the existing power electricity grids, which need to be rapidly evolved [1]. The internet-of-things (IoT) is one of the major driving forces behind the next generation power electricity grids, termed as smart grids (SGs). The IoT refers to the use of advanced digital information technologies, such as sensing, data communications, and actuation [2], which are coordinated and controlled in a completely automatic manner, without any human intervention, by an end-to-end platform. The integration of this platform with the power electricity grid generates many new opportunities, such as the ability to manage the electricity demand in a sustainable, reliable, and economic manner. More specifically, SGs, by properly exploiting the new capabilities provided by the IoT, are envisioned to achieve:

- Environmental protection
- Steady availability of power,
- Energy sustainability,
- Environmental protection,
- Prevention of failures, as well as well as optimized operational expenses (OPEX) of power production and distribution, and reduced future capital expenses (CAPEX) for thermal generators and transmission networks.

For this purpose, each consumption/production location, as well as several components of the transmission and distribution network, such as relays, switches, transformers, and substations, have to be equipped with a smart meter for monitoring and measuring the bi-directional flow of power and data, while supervisory control and data acquisition (SCADA) systems are needed to control the grid operation [3]. Data mining is the standard process to harvest useful information from a stream of data, such as users' electricity demand, renewable power generation, and electric vehicles (EVs) state of battery, and transform it into an understandable structure for further use. The data mining process is based on the utilization of algorithms for discovering patterns among the data [4]. Efficient and effective data mining is crucial towards the optimized operation of the SG, since it strongly affects the related costs, the reliability of the grid and the service interruptions, the provided level of security, and the self-organization capability. Indeed, most of the research related to data mining in SGs deal with predictive analytics and load classification (LC), which are necessary for the load forecasting, bad data correction, anomaly detection, determination of the optimal energy resources scheduling, and setting of the power prices [5].

In order to deal with the stochastic nature of the SG, the data volume, variety, and velocity, as well as and the requirement for real-time learning/decision making and collective awareness, the SG demands advanced data analytic techniques, big data management, and powerful monitoring techniques [6]. Various techniques such as artificial intelligence, distributed and HPC, simulation and modeling, data network management, database management, and data warehousing are to be used to guarantee smooth running of SGs. The main challenges of efficient data processing in SGs is the selection, deployment, monitoring, and analysis of aggregated data in real-time [7]. The efficient processing of the produced vast amount of data requires increased data storage and computing resources, which imply the need for high performance computing (HPC) techniques.

In this work, it is highlighted that Big Data Analytics (BDA) can provide efficient solutions in specific problems related to data processing in SGs, which are described in the next sections. Section 2 presents the main challenges in failure detection using data analytics. Data driven demand side management (DSM) is discussed in Section 3. Section 4 focuses on predictive analytics for electric vehicles. Section 5 is dedicated to privacy and security challenges, while Section 6 concludes the paper.

2. Failure Protection

Insufficient monitoring and control of the power flow can increase the possibility of failure (e.g., due to load synchronization, overloading, congestion, etc.). The power grid, which is consisted of multiple components such as relays, switches, transformers, and substations, must be carefully monitored. Due to lack of robustness, the power grid is running to capacity and has become prone to failures caused by overloads, human errors, and natural disasters. Therefore, the SG requires intelligent real-time monitoring techniques in order to be capable of detecting abnormal events, finding their location and causes, and most importantly predicting and eliminating faults before they happen. This self-healing behavior, renders the power grid a real "immune system", which is one of the most important characteristics of a SG framework [8], [9]. One major problem of self-healing control is the "uninterrupted power supply problem", that is, real-time monitoring of network operation, prediction of the state power grid, timely detection, rapid diagnosis and elimination of hidden faults, without human intervention or only in a few cases. With self-healing capacity, the SG can also monitor a variety of disturbances, compensate for reactive power, re-distribute the trend, and avoid expansion of accidents.

Critical events in SGs usually have temporal-spatial properties, which calls for temporal-spatial analysis [10]. A promising approach of BDA for fault detection, identification and causal impact analysis has been proposed in [11], which manages to keep comprehensive information from synchrophasor measurements in spatial and temporal domains, while substantially reducing data volume. The derived scheme manages to achieve a high level of situational awareness, which is investigated based on hidden Markov model (HMM). Interestingly, the proposed scheme has been tested on IEEE 39-bus and IEEE 118-bus systems. Also, five representative fault types are employed for evaluating the proposed characterization approach, i.e., generator grounding, load loss, generator outage, single transmission line outage, and three-phase transmission line outage.

3. Data Driven Demand Side Management

Energy management in a SG is a complicated, multi-variable procedure, since the latter enables an interconnected power distribution network by allowing a two-way flow of both power and data, as illustrated in Fig. 1. This contrasts with the traditional power grid, in which the electricity is generated at a central source and then distributed to consumers. Thanks to the bi-directional flow of information and power between suppliers and consumers, the grids become more adaptive to the increased penetration of distributed energy sources, encouraging also users' participation in energy savings and cooperation through the DSM mechanism [12], [13].

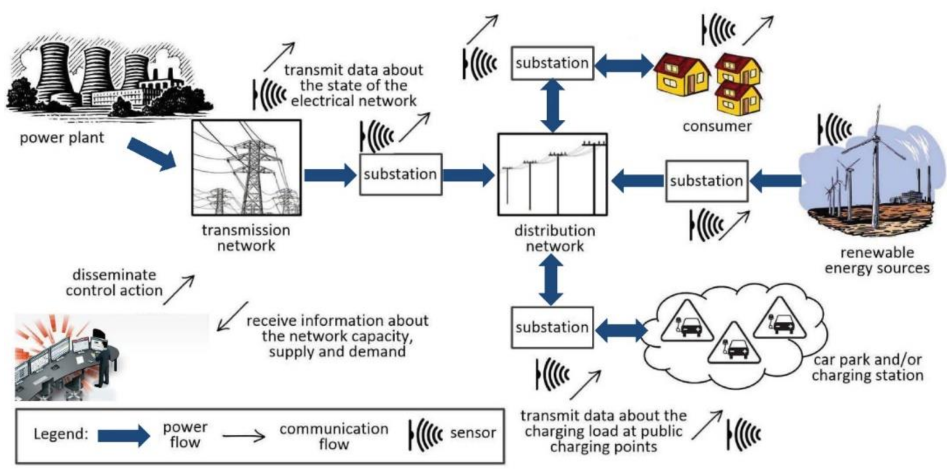


Fig. 1: The integration of electrical and communication network in smart grid.

DSM can be applied to both residential (e.g., cooling, heating, EVs charging, etc.) and industrial loads and includes three different concepts: i) energy consumption reduction, ii) energy consumption (or production) shifting to periods of low (or high) demand, and iii) efficient utilization of storage systems. It should be noticed here that plug-in EVs can be considered as storage devices, while the careful scheduling of their charging and discharging can benefit both their owners and the utilities. Obviously, this further increases the parameters that the DSM algorithms have to take into account, such as the EVs charging profiles. Consequently, the associated complexity is also increased, creating at the same time storage capacity prediction problems [14]. Thus, a crucial issue in SGs is how to manage DSM in order to reduce peak electricity load, utilizing at the same time renewable energies and storage systems more efficiently. Finally, effectiveness of DSM algorithms depends critically on demand, price, load, and renewable energy forecasting, which highlights the need for sophisticated signal processing techniques [15].

DSM can be realized in three ways, namely direct load control (DLC), autonomous demand response (DR), and/or dynamic pricing. Due to users' demand for privacy, DLC, which is a completely centralized approach, is not appropriate for residential electrical load control [12]. On the other hand, autonomous DR is a very important mechanism for the future SGs, since it enables the automatic scheduling of the energy consumption. Also, if autonomous DR is combined with an incentive-based consumption scheduling scheme, it leads to promising results on reducing the energy costs and the peak to average power ratio. Similarly to autonomous DR, dynamic pricing does not require users to allow direct access of the operator to their electrical appliances. Also, it does not require nor requires users to declare their usage hours before turning on the switch. However, one major problem in dynamic power pricing is load synchronization, especially when there are limitations on the exchanged information. Since the power provider sets the power price selfishly without a proper contract on time-of-use and prices between operator and users, it is difficult for the operator to accurately predict and set an appropriate power price [13].

The electricity demand and renewable production in the SG environment is affected by several factors, including weather conditions, micro-climatic variations, time of day, random disturbances, electricity prices, DSM profiles, renewable energy sources, storage cells, micro-grids, and the development of EVs. High forecasting accuracy accommodates the generation and transmission planning, i.e., deciding which power plants to operate and how much power should be generated by them at a specific time-period, with the aim to reduce the operating cost and increase the reliability. It also enables the utilities to successively estimate the electricity cost and correctly set the electricity prices, capturing the interdependency between the energy demand and the prices [16]. A typical example of this interdependency is load-synchronization, where a large portion of load is shifted from hours of high prices to hours of low prices, without significantly reducing the peak-to-average ratio [17]. In general, the reliability of the electricity grid could be enhanced if the users were aware of the effects of their personal energy use on the total consumption and overloading.

Considering the above, the optimized DSM highly depends on the quality and reliability of the data collected. Also, data mining and predictive analytics tools become essential for the effective management and utilization of the available sensor data [18]. This is because effective DSM usually relies on short-term power supply, consumption, and power price forecasting. Additionally, the sensor data contains important correlations, trends, and patterns that need to be exploited for the optimization of the energy consumption and supply, among others [19].

4. Predictive Control for Electric Vehicles Power Demand

Plug-in electric vehicles (PEVs) can substantially reduce the greenhouse gas emissions, due to their lower dependency on fossil fuel [20]. Also, PEVs can substantially reduce the corresponding expenses, which also depends on efficient battery charging. PEVs power demand is fundamentally different to other types of power demand, e.g., residence, since it is only known after random PEVs arrivals [21].

To this end, a novel method has been proposed in [22], in order to accurately estimate charging load using a fuzzy logic method, that accounts for random driver behaviors and statistical distribution of different vehicle types. Also, a practical scenario is investigated in [21], where unlike in related works, no assumptions are made about the probability distribution of PEVs. More specifically, joint PEV charging scheduling and power control is issued by the development a novel model predictive control-based computational algorithm that can achieve a globally optimal solution.

In general, accurate PEVs power demand estimation depends on many parameters, such as speed information, roads congestion, the level of charge in each PEV, the PEV's location, historical data, tire pressure, etc. Also, different use-case scenarios have to be considered, such as plug-in hybrid electric vehicles (PHEVs), i.e., vehicles that use a mix of electric motor and combustion engine, self-driven PEVs. For example, joint optimization of route planning and charging planning of PEVs is a challenging problem [20], while temporal and spatial load shifting options have to be jointly considered. Consequently, exploitation of BDA for accurate predicting of the charging loads is a promising direction that needs to be further investigated.

5. Security and Privacy Issues in the Smart Grid

Security, privacy, and confidentiality are major challenges for the application of BDA on SG data processing [23], [24].

5.1. Privacy

In order to ensure privacy, there are two different approaches, i.e.,

- Approach 1: data processing before sending it to the utility provider and
- Approach 2: modifying the actual user demand.

According to the first approach, which is the most common in the available literature, privacy of end users can be guaranteed by data aggregation, data anonymization, and data obfuscation which is used in most SG architectures. Data aggregation is based on aggregating power measurements over a group of households so that the provider cannot have knowledge of individual consumption [25]. In data anonymization, pseudonyms are used instead of the real identities [26]. The aggregation can be performed by a trusted third party, when necessary. Data obfuscation refers to the perturbation of metering data by adding noise [27]. Note that the designed data architectures must be multi-tenant, following one of the three different approaches for such architectures, namely the separate databases, separate schemas, or shared schemas [28]. Although the first approach is quite practical, its main disadvantage is that it still suffers from a privacy risk, since the operator is able to install a sensor for directly monitoring a residence or a business. Even worse, extra sensors can be placed by intelligent agencies or thieves. Also, data obfuscation method may provoke a mismatch between the real energy consumption and the reported values.

The second approach is investigated in [29]-[31], among others. In the pioneering recent work [32], privacy is measured by the information leakage rate, which denotes the average mutual information between the user's real energy consumption and the energy requested from the grid, which the smart meter reads and reports to the utility provider. The minimum information leakage rate is a computable information theoretic single-letter expression, when the battery capacity is infinite or zero. Interestingly, it is illustrated that the information leakage rate decreases with increasing availability of a renewable energy source.

5.2. Security

Security is a challenging problem from both consumers' and electrical companies' perspective, since the hackers of systems located in the cloud cannot be easily traced. Also, data injection attacks, which aim to corrupt the estimate that the operator obtains, are among the most important concerns. Authentication, encryption, trust management, and intrusion and attack detection are important security mechanisms that can prevent, detect and mitigate such network attacks [33], [34].

The cybersecurity threats to which the SG is exposed requires a multidisciplinary approach, combining cryptography advanced machine learning, and information theoretic security [35]. Using machine learning the measurements are classified either as secure or attacked [36]. Although cryptography and machine learning are well-known concepts, information theoretic security is SGs is a relatively new approach, which aims to quantify the information loss sue to the attack, as well as the probability of attack detection.

6. Conclusions

In this paper, we have presented specific problems of SGs that can be resolved using data analytics processing and exploitation, as well as the proposed solutions, approaches, and concepts. More specifically, it has been recognized that data analytics can offer a feasible solution to efficient failure detection, demand side management, and EVs predictive analytics. In order to deal with the extreme size of data, the smart grid requires the adoption of advanced data analytics, big data management, and powerful monitoring techniques. Finally, we have elaborated on several challenging issues that are related to privacy and security, which call for a multidisciplinary approach, combining cryptography advanced machine learning, and information theoretic security.

References

[1] S. F. Bush, S. Goel, G. Simard, "IEEE Vision for Smart Grid Communications: 2030 and Beyond Roadmap," IEEE Vision for Smart Grid Communications: 2030 and Beyond Roadmap, vol., no., pp.1-19, Sep. 2013

[2] R. Gore and S. P. Valsan, "Big Data challenges in smart Grid IoT (WAMS) deployment," Proceedings of the 8th International Conference on Communication Systems and Networks (COMSNETS), Bangalore, 2016, pp. 1-6.

[3] A. Ukil and R. Zivanovic, "Automated analysis of power systems disturbance records: Smart Grid big data perspective,"

Proceedings of the IEEE Innovative Smart Grid Technologies - Asia (ISGT ASIA), Kuala Lumpur, 2014, pp. 126-131.
[4] G. Chicco, R. Napoli, P. Postolache, M. Scutariu and C. Toader, "Customer characterization options for improving the tariff offer," IEEE Transactions on Power Systems, vol. 18, no. 1, pp. 381-387, Feb. 2003.
[5] Z. Vale, H. Morais, S. Ramos, J. Soares and P. Faria, "Using data mining techniques to support DR programs definition in smart grids," Proceedings of the IEEE Power and Energy Society General Meeting, San Diego, CA, 2011, pp. 1-8.
[6] P. D. Diamantoulakis, V. M. Kapinas, and G. K. Karagiannidis, “Big Data Analytics for Dynamic Energy Management in Smart Grids,” Big Data Research, vol. 2, no. 3, pp. 94–101, Sep. 2015.
[7] J. Baek, Q. H. Vu, J. K. Liu, X. Huang and Y. Xiang, "A Secure Cloud Computing Based Framework for Big Data Information Management of Smart Grid," in IEEE Transactions on Cloud Computing, vol. 3, no. 2, pp. 233-244, April-June 1 2015.
[8] J. Pitt et al., "Transforming Big Data into Collective Awareness," in Computer, vol. 46, no. 6, pp. 40-45, June 2013.
[9] D. Jia, X. Meng and X. Song, "Study on technology system of self-healing control in smart distribution grid," Proceedings of the International Conference on Advanced Power System Automation and Protection, Beijing, 2011, pp. 26-30.
[10] Z. Fu, M. Almgren, O. Landsiedel and M. Papatriantafilou, "Online temporal-spatial analysis for detection of critical events in Cyber-Physical Systems," Proceedings of the IEEE International Conference on Big Data (Big Data), Washington, DC, 2014, pp. 129-134.
[11] H. Jiang, X. Dai, D. W. Gao, J. J. Zhang, Y. Zhang and E. Muljadi, "Spatial-Temporal Synchrophasor Data Characterization and Analytics in Smart Grid Fault Detection, Identification, and Impact Causal Analysis," IEEE Transactions on Smart Grid, vol. 7, no. 5, pp. 2525-2536, Sept. 2016.
[12] P. Samadi, H. Mohsenian-Rad, V. W. S. Wong and R. Schober, "Real-Time Pricing for Demand Response Based on Stochastic Approximation," in IEEE Transactions on Smart Grid, vol. 5, no. 2, pp. 789-798, March 2014.
[13] P. D. Diamantoulakis PD, K. N. Pappi, P. Y. Kong, G. K. Karagiannidis, Game Theoretic Approach to Demand Side Management in Smart Grid with User-Dependent Acceptance Prices. In: Proc. 2016 IEEE 84th Vehicular Technology Conference (VTC-Fall); 2016. p. 1–5.
[14] X. Wang, W. Tian, J. He, M. Huang, J. Jiang and H. Han, "The Application of Electric Vehicles as Mobile Distributed Energy Storage Units in Smart Grid," Proceedings of the Asia-Pacific Power and Energy Engineering Conference, Wuhan, 2011, pp. 1-5.
[15] S. C. Chan, K. M. Tsui, H. C. Wu, Y. Hou, Y. C. Wu and F. F. Wu, "Load/Price Forecasting and Managing Demand Response for Smart Grids: Methodologies and Challenges," IEEE Signal Processing Magazine, vol. 29, no. 5, pp. 68-85, Sept. 2012.
[16] A. Motamedi, H. Zareipour and W. D. Rosehart, "Electricity Price and Demand Forecasting in Smart Grids," IEEE Transactions on Smart Grid, vol. 3, no. 2, pp. 664-674, June 2012.
[17] A. H. Mohsenian-Rad and A. Leon-Garcia, "Optimal Residential Load Control With Price Prediction in Real-Time Electricity Pricing Environments," in IEEE Transactions on Smart Grid, vol. 1, no. 2, pp. 120-133, Sep. 2010.
[18] Z. Fan, Q. Chen, G. Kalogridis, S. Tan and D. Kaleshi, "The power of data: Data analytics for M2M and smart grid," Proceedings of the 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), Berlin, 2012, pp. 1-8.
[19] R. Mallik, N. Sarda, and H. Kargupta, “Distributed Data Mining for Sustainable Smart Grids,” Proceedings of the ACM Sustainable KDD Workshop, ACM, 2011.
[20] P. Y. Kong and G. K. Karagiannidis, "Charging Schemes for Plug-In Hybrid Electric Vehicles in Smart Grid: A Survey," in IEEE Access, vol. 4, pp. 6846-6875, 2016.
[21] Shi, Y., et al. "Model Predictive Control for Smart Grids with Multiple Electric-Vehicle Charging Stations." arXiv preprint arXiv:1708.07626, Aug. 2017.
[22] J. Tan and L. Wang, "Integration of Plug-in Hybrid Electric Vehicles into Residential Distribution Grid Based on Two-Layer Intelligent Optimization," IEEE Transactions on Smart Grid, vol. 5, no. 4, pp. 1774-1784, Jul. 2014.
[23] M. Yigit, V. C. Gungor, and S. Baktir, “Cloud computing for smart grid applications,” Comput. Netw., vol. 70, pp. 312–329, Sep. 2014
[24] A. Kasper. Legal Aspects of CyberSecurity in Emerging Technologies: Smart Grids and Big Data. In: Kerikme T, editor. Regulating eTechnologies in the European Union. Springer International Publishing; 2014. p. 189–216.
[25] F. Li, B. Luo, and P. Liu, “Secure and privacy-preserving information aggregation for smart grids,” International Journal of Security and Networks (IJSN), special issue on security and privacy in smart grids, Vo. 6, No. 1, 2011, pp. 28-39.
[26] C. Efthymiou and G. Kalogridis, "Smart Grid Privacy via Anonymization of Smart Metering Data," 2010 First IEEE International Conference on Smart Grid Communications, Gaithersburg, MD, 2010, pp. 238-243.
[27] Y. Kim, E. C. H. Ngai and M. B. Srivastava, "Cooperative state estimation for preserving privacy of user behaviors in smart grid," 2011 IEEE International Conference on Smart Grid Communications (SmartGridComm), Brussels, 2011, pp. 178-183.
[28] S. Rusitschka, K. Eger and C. Gerdes, "Smart Grid Data Cloud: A Model for Utilizing Cloud Computing in the Smart Grid Domain," Proceedings of the IEEE International Conference on Smart Grid Communications, Gaithersburg, MD, 2010, pp. 483-488.
[29] O. Tan, D. Gunduz and H. V. Poor, "Increasing Smart Meter Privacy Through Energy Harvesting and Storage Devices," in IEEE Journal on Selected Areas in Communications, vol. 31, no. 7, pp. 1331-1341, July 2013.
[30] O. Tan, J. Gómez-Vilardebó and D. Gündüz, "Privacy-Cost Trade-offs in Demand-Side Management With Storage," in IEEE Transactions on Information Forensics and Security, vol. 12, no. 6, pp. 1458-1469, Jun. 2017.
[31] S. Li, A. Khisti and A. Mahajan, "Privacy-optimal strategies for smart metering systems with a rechargeable battery," 2016 American Control Conference (ACC), Boston, MA, 2016, pp. 2080-2085.
[32] G. Giaconi, D. Gündüz and H. V. Poor, "Smart Meter Privacy with Renewable Energy and an Energy Storage Device," in

IEEE Transactions on Information Forensics and Security, vol. PP, no. 99, pp. 1-1.
[33] G. N. Ericsson, "Cyber Security and Power System Communication—Essential Parts of a Smart Grid Infrastructure," in IEEE Transactions on Power Delivery, vol. 25, no. 3, pp. 1501-1507, July 2010.
[34] E. Ancillotti, R. Bruno, and M. Conti, "The role of communication systems in smart grids: Architectures, technical solutions and research challenges," Comput. Commun., vol. 36, no. 17, pp. 1665–1697, Nov./Dec. 2013.
[35] K. Sun, I. Esnaola, S. Perlaza, H. V. Poor, SUN, Information-Theoretic Attacks in the Smart Grid, arXiv preprint arXiv:1708.07810, Aug. 2017.
[36] M. Ozay, I. Esnaola, F. T. Yarman Vural, S. R. Kulkarni and H. V. Poor, "Machine Learning Methods for Attack Detection in the Smart Grid," in IEEE Transactions on Neural Networks and Learning Systems, vol. 27, no. 8, pp. 1773-1786, Aug. 2016.

Panagiotis D. Diamantoulakis was born in Thessaloniki, Greece, in 1989. He received the Diploma Degree (5 years) and his PhD in Electrical and Computer Engineering from the Aristotle University of Thessaloniki, Greece, in 2012 and 2017, respectively. His current research interests include wireless communications, wireless power transfer, big data for smart grids, optimization theory and applications, and game theory.

During 2014-2016, he was a visitor researcher at the department of Electrical and Computer Engineering at Khalifa University, UAE, and at the Institute for Digital Communications (IDC) of the Telecommunications Laboratory (LNT) at Friedrich-Alexander- Universität Erlangen-Nürnberg (FAU), Germany. In 2015, he received the student travel grant for the International Workshop on Optical Wireless Communication (IWOW), Istanbul, Turkey.

He is co-author of a chapter titled "Trade-offs in Wireless Powered Communications", in the book Wireless Power Transfer Algorithms, Technologies and Applications in Ad Hoc Communication Networks, Springer, 2017. He is Editor of Journal of Communications and Information Networks and Guest Editor of Applied Sciences for the Special Issue "Optical Wireless Communications". He was Member of the International Advisory Committee in the International Conference on Big Data and Data Analytics (ICBDDA-17). He has served as a reviewer in various IEEE journals and conferences and as member of the technical program committee of various international IEEE and non-IEEE conferences. Also, he was an exemplary reviewer in IEEE Communication Letters for 2014 (top 3% of reviewers).

George K. Karagiannidis is currently Professor in the Electrical & Computer Engineering Dept. and Director of Digital Telecommunications Systems and Networks Laboratory. He is also Honorary Professor at South West Jiaotong University, Chengdu, China.

His research interests are in the broad area of Digital Communications Systems and Signal processing, with emphasis on Wireless Communications, Optical Wireless Communications, Wireless Power Transfer and Applications, Molecular and Nanoscale Communications, Stochastic Processes in Biology and Wireless Security.

He is author or co-author of more than 450 technical papers published in scientific journals and presented at international conferences. He is also co-author of the book "Advanced Optical Wireless Communications Systems", Cambridge Publications, 2012.

He was Editor in IEEE Transactions on Communications, Senior Editor of IEEE Communications Letters, and several times Guest Editor in IEEE Selected Areas in Communications. From 2012 to 2015 he was the Editor-in Chief of IEEE Communications Letters.

Dr. Karagiannidis is one of the highly-cited researchers across all areas of Electrical Engineering, recognized as 2015 and 2016 Thomson Reuters highly-cited researcher.

A scalable and interoperable platform for transactional demand reduction

Javad Fattahi and Henry Schriemer
School of Electrical Engineering and Computer Science, University of Ottawa
Javad.fattahi@uottawa.ca , hschriem@eecs.uottawa.ca

1. Introduction

Given the inherent variability of typical renewable energy sources (RES), such as wind and photovoltaic solar energy, their further grid penetration imposes increasing challenges to power system operation and control [1]. The intersection of load profile indeterminacy with intermittent RES generation requires greater flexibility in prosumer (proactive consumers) to mitigate problems that may arise at the point of common coupling with the grid. To address, for example, grid voltage and frequency regulation issues, demand response (DR) approaches may be exploited.

Existing DR solutions can be grouped into centralized and hierarchical approaches [2]. The centralized approach requires distributed grid monitoring, and the data is used to optimize some operation metric across a specific interval. Optimization is driven by specific strategies, such as direct load control, which are based on agreements between distribution system operators (DSO) and their customers to remotely regulate certain loads such as heating, ventilation and air conditioning (HVAC) [3]. By contrast, hierarchical, or decentralized, DR also embeds local agents with autonomy and control intelligence, for example with HVAC controller units responding on the basis of aggregate local demand. Hierarchical DR schemes can be implemented through a master-slave approach where local controllers are responsible for balancing local generation and consumption in a global context [4].

There are challenges to the implementation of both control schemes, not only in consumer privacy and cyber security [5], but also in their effective realizations. DR has been used effectively with high consumption facilities to maintain power flow flexibility but DR attempts at the residential side have not yet proven effective. There is little consideration of possible demand response contribution to dynamic system state regulation, with the principle focus being static upside-down load management at the transmission level rather than on sparse and distributed loads and generation at the grid edge [6,7]. Furthermore, in terms of control methodology, the focus is almost entirely on direct load control, which is poor in scalability and convergence time because of the huge number of appliances to be controlled [8].

We address these challenges with dynamic DR through transactional balance between power demand and supply, including distributed generation and storage, at the grid edge. We use an autonomous distributed architecture with real-time communication between a transformer-level demand controller and its network of home energy management systems (HEMS). Within this Grid Edge Active Transactional Demand Response (GREAT-DR) architecture, we seek to maximize electricity demand reduction by optimally scheduling the operation of each HEMS, subject to constraints set by their users.

Our proposed solution brings localized demand response and smart grid control to the distribution utility, and to their customers, while preserving privacy and user control. It does this with an open standards approach, using as an interoperability protocol the IEEE 2030.5-2013 Smart Energy Profile 2.0 Application Protocol Standard [9]. We consider a transactional demand response (TDR) system within the distribution network itself, at the transformer level serving residential customers. As insufficient oversight of TDR could lead to unprecedented invasions of customer privacy, the monitoring of residential load and supply needed to drive TDR negotiation and optimization that is mediated by the HEMS intelligence is firewalled by design.

2. System Overview

A. Physical requirements

The GREAT-DR system architecture is depicted in Figure 1. There are two user communities, namely Utility staff operating the distribution network, and the residential homeowners within the transactive network. Three key pieces of technology are being developed: the Transformer Agent (TA), the Customer Agent (CA), and the home energy management systems controller (HEMSC).

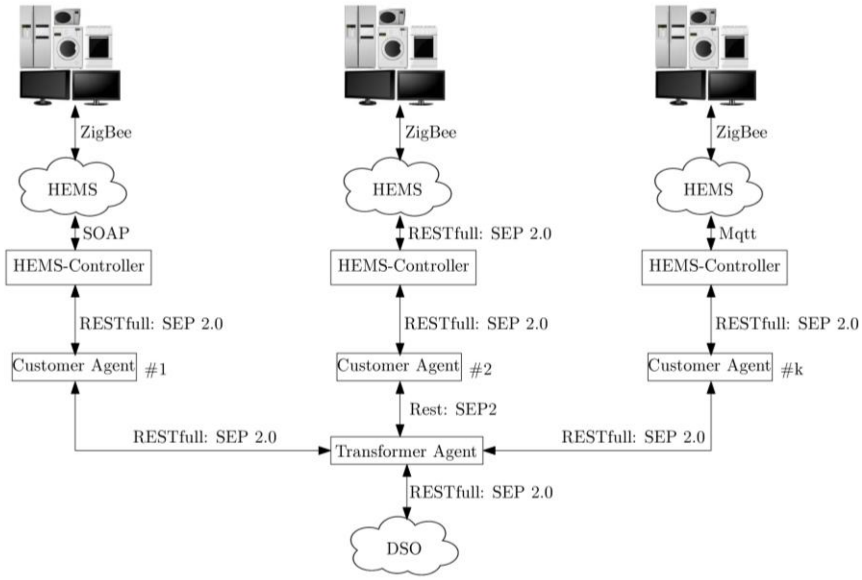


Figure 1. The transactional demand response structural architecture

The TA is physically located adjacent to the neighborhood distribution transformer. The TA is a micro server that monitors the local grid on the low-voltage side of the transformer and communicates with CA devices to coordinate DR actions. The TA is also in communication with the distribution system operator (DSO) central control room (CCR) for DR control and health monitoring of the transformer and power network states. The CA is physically located at the customer premise near the service entrance, and is a trusted utility asset capable of performing local power measurements. This enables DR actions undertaken by third-party HEMS to be independently validated. The CA (client) communicates with the TA (server) to coordinate DR actions, and it controls exposure to the customer's HEMSC, therefore preserving privacy by design. Furthermore, the CA is designed as a micro server to communicate with the HEMSC as a client, and to exchange data via the Smart Energy Profile 2.0 (SEP 2.0) telemetry protocol.

The HEMSC, which is a client located at the customer premise, is responsible for integrating a wide variety of customer-premise devices as shown in Figure 1. It implements an IEEE 2030.5 standards-compliant interface to proprietary third-party vendor energy management technology. It translates CA SEP 2.0 DR commands and other information into the formats and commands required by each technology-specific controller, contains embedded intelligence to negotiate via the CA with the TA, and provides a customer interface to input user preferences and constraints.

B. Cyber security and reliability

The system must be secure and reliable on both the customer and DSO sides. Specifically, customer access to DR devices must be strictly through (whether directly or indirectly) the HEMSC (typically via the user interface), and customer privacy must be maintained (limiting the nature of customer data that may be used). Our GREAT DR structural architecture promotes interoperability by exploiting IEEE 2030.5 requirements, using HTTPS as the data transfer protocol, and XML and Efficient XML Interchange (EXI) as the data exchange format, as recommended by SEP 2.0, which is the application layer protocol that can run on top of different internet technologies within the IPv6 protocol suite. SEP 2.0 uses a representational state transfer (REST) interface exploiting a common information model (CIM). CIM compliance is important when providing demand response to diverse DSOs. IEEE 2030.5 has a residential focus and is complementary to OpenADR, which traditionally focused on commercial and industrial customers [10].

Non-authorized users must be prevented from gaining system control. A secure login ID/Password operating over an encrypted channel on public or private IP networks is considered sufficiently secure to meet IEEE 2030.5 requirements. We deploy Transport Layer Security 1.2 (TLS) to provide confidentiality in message exchange, to ensure authenticity of the different parties communicating and to ensure integrity of the messages are being sent. Furthermore, public key infrastructure (PKI) is used to achieve cryptographic non-repudiation. PKI can be a relevant service in a transactional energy scenario to establish a secure data tunnel (TLS 1.2) with distributed micro TA and CA servers.

The system is designed to be scalable in both hardware and software. Although the system does not employ redundancy in order to achieve reliability, its micro-server structure within a RESTful architecture enables future expansion.

3. Data Model and Ontology

Interoperability is required for the implementation of the Smart Grid. According to IEEE 610, interoperability is the ability of two or more networks, systems, applications, components or devices from the same vendor, or different vendors, to exchange and subsequently use that information in order to perform required functions [11]. This is fundamentally an open standards approach, predicated on the use of specified data formats and communication protocols (syntactic interoperability) to exchange data with unambiguous meaning (semantic interoperability), as referenced by a CIM.

The International Electrotechnical Commission (IEC) has decided that the SEP 2.0 protocol shall be the future data model for the IEC 62746 standard, which describes the interface between the customer and the Smart Grid power management technologies. The CIM, which constitutes the building block of the SEP 2.0 specification, is based on the model recommended by IEC 61970 standard. Therefore, the main CIM concepts can be applied both within the customer domain and at the interface between the customer and the grid. In particular, SEP 2.0 provides a collection of Function Sets (FS), with their related resources and attributes described in detail. SEP 2.0 also provides a syntactical representation in the form of an XML Schema Definition (XSD). The XSD formally specifies how to describe the elements and attributes in a FS, which permits automatic validation to ensure conformance with the specifications.

4. Firmware architecture

The purpose of the HEMSC is to manage the scheduling of smart loads based on the consumption mode, comfort level and load priorities set by the consumer. To achieve this, and to reduce implementation complexity, a denotational control approach, like fuzzy control, can be exploited in such a way that total household consumption is maintained below the demand limits specified by the DSO. Our HEMSC is designed to be compatible with HEMS from different vendors. As shown in Figure 1, the HEMSC communicates with appliances using an application program interface (API), using web services like simple object access protocol (SOAP), RESTful, and message queue telemetry transport (MQTT).

The HEMSC must translate TDR data from any particular technology-specific protocol into that of the SEP 2.0 FS. In that sense, it imposes compatibility on extant technology to achieve system-wide interoperability, and effectively establishes compliant HEMS. In our architecture, the HEMSC and CA are client and server, respectively. The HEMSC uses a multi-layer architecture for communicating, monitoring and controlling the devices to which it is connected. Its firmware supervises overall system operation, manages multiple layers, and allows local and remote access of devices in its network.

The HEMSC system is comprised of four firmware layers: (i) graphical user interface (GUI), (ii) data management, (iii) translation and ontology, and (iv) connectivity. This multi-layer structure enables us to update each layer individually without interrupting the other layers. The first layer consists of two fundamental components: (a) the GUI, and (b) user management. The GUI is a web-based dashboard to show device settings and consumption. Authenticated users can also control these devices through an on-site interface. Regarding user management, role-based control is implemented to allow varying levels of access.

The data management layer is accomplished using an algorithm designed for monitoring and control of the hardware and appliances. In addition to DR, the algorithm enables Smart Grid applications like price-based management, planning and scheduling, behavior pattern analysis, load management, as well as alarm/notifications.

In the translation and ontology layer, a distributed agent model is used to deploy several agents, including device discovery, monitoring (sensor), control (e.g., thermostat, lighting load and plug load), network, and platform agents. All agents communicate over an information exchange bus (IEB). This layer is responsible for detecting the presence of any device in a house, identifying it, and launching the necessary monitoring and control. With this approach, there is no need to manually identify each device, as all agents are automatically generated to communicate with the device after discovery by HEMSC. This layer applies the XSD to all necessary data, and then posts the FSs with their elements and attributes to the server (CA).

The connectivity layer ensures communication between all other layers, and with the physical hardware and devices in the network. It provides a network and data firewall to protect customer security and privacy. It sends qualified data to the CA in order to perform the TDR requirements, such as the DRResponse FS. Finally, HEMSC encompasses different communication technologies such as; wireless fidelity (WiFi), local area network (LAN), ZigBee, serial peripheral interface (SPI) and Modbus.

Algorithm 1. Abbreviated TDR algorithm.

TA side:

1. If new DR request from DSO or local condition of transformer then go to 3.
2. If the number of negotiation is less than *N*, otherwise go to 7.
   2.1. If total DR amount is not satisfied the go to 4 otherwise go to 7.
3. TA initiates the TDR negotiation with active CAs.
4. Drop the CAs who contribute to DR request more that allocated request, then go to 5.
5. Optimized load dispatching then,
6. Allocate DR request to each CA, then go to 1.
7. Terminate the negotiation and make DR mandatory.

CA side:

1. CA GET DR request from TA.
2. If DR request is new go to 3 otherwise go to 1.
3. Validate the data with SEP 2.0 XSD.

HEMSC side:

1. HEMSC GET DR request.
2. If *drmandatory* is True then go to step 6.
3. If DR request is new go to step 4, otherwise go to 1.
4. Check the availability of load reduction.
5. POST availability of DR to the CA.
6. Terminate the negotiation and apply DR request.
7. Go to step 1.

5. Transactional algorithm

An abbreviated overview of an elementary TDR algorithm is given in Algorithm 1, for illustration. If the transformer condition exceeds some threshold, or a DR request is received from the DSO CCR, the TA (server), initiates the TDR negotiation with active household CAs (clients). The TA uses an optimization method to apportion load reduction between households. The optimization problem is dynamically solved by minimizing an objective function that captures the tradeoff between DR availability and the likelihood of achieving the desired demand reduction, subject to privacy by design constraints, within the transaction time interval. An ongoing optimized state is achieved via continuous transactional negotiation between the global intelligence at the TA upper hierarchy level, and the distributed intelligence across the network of CAs/HEMSCs at the lower hierarchy level.

After allocating DR requests to each CAs, it sends the requested DR settings through the EndDeviceControl FS. All active CAs, as clients, regularly receive data from the TA server (via GET commands). On the CA side, as a server for its HEMSC, the data are validated with SEP 2.0 XSD and prepared for HEMSC use. The connection between CA and HEMSC is firewalled and established via a specific private port.

The HEMSC, as a client to its CA, gets the DR request and first checks the likelihood of load reduction by rescheduling and/or load shedding. For control of renewable sources (generation and storage), DER FSs are used. The bidirectional (GET/PUT commands) DERAvailability, DERCapability, and DERSetting FSs provide sufficient scope to control and monitor both PV inverters and electrical storage. After receiving a DR request from the TA, which may include aggregate data at earlier times, a decision as to how to implement the request is made by the HEMSC, subject to immediate local conditions, using model predictive control. GET/PUT commands are consumed by their respective devices in a continuous heartbeat established by the transaction time interval set by the TA.

After evaluating available sheddable loads and possible generation settings, the HEMSC posts the required data to the CA, and the CA subsequently posts it to the TA. The HEMSC response to the DR request is enveloped in the DRResponse and Loadshedavailability FSs. At the TA side, if in the first negotiation run the requested demand reduction target was satisfied, then the TDR negotiation is terminated, otherwise the new data acquired via the CAs is used to advance the transaction. Eventually, if no compromise occurs after N iterations, the last calculated request will be applied to households by making the drmandatory element true in the EndDeviceControl FS. The program then begins the next transaction cycle, and a new round of optimization and negotiation commences.

Acknowledgements

This project is funded in part by Ontario's Smart Grid Fund; Hydro Ottawa Limited; Energate Inc.; Tabuchi Electric Company of America, LTD; and Panasonic Eco Solutions Canada Inc. The views expressed herein are the views of the authors and do not necessarily reflect those of the Province, the Recipient, and any other collaborator or sponsor.

References

[1] Peng, M., L. Liu, and C. Jiang, *A review on the economic dispatch and risk management of the large-scale plug-in electric vehicles (PHEVs)-penetrated power systems.* Renewable and Sustainable Energy Reviews, 2012. **16**(3): p. 1508-1515.
[2] Olivares, D.E., C.A. Cañizares, and M. Kazerani. *A centralized optimal energy management system for microgrids*. in *2011 IEEE Power and Energy Society General Meeting*. 2011.
[3] Ruiz, N., I. Cobelo, and J. Oyarzabal, *A Direct Load Control Model for Virtual Power Plant Management.* IEEE Transactions on Power Systems, 2009. **24**(2): p. 959-966.
[4] Tsikalakis, A.G. and N.D. Hatziargyriou, *Centralized Control for Optimizing Microgrids Operation.* IEEE Transactions on Energy Conversion, 2008. **23**(1): p. 241-248.
[5] Yan, Y., et al., *A survey on cyber security for smart grid communications.* IEEE Communications Surveys & Tutorials, 2012.
[6] Molina-Garcia, A., F. Bouffard, and D.S. Kirschen, *Decentralized demand-side contribution to primary frequency control.* IEEE Transactions on Power Systems, 2011. **26**(1): p. 411-419.
[7] Schisler, K., T. Sick, and K. Brief. *The role of demand response in ancillary services markets*. in *Transmission and Distribution Conference and Exposition, 2008. T&D. IEEE/PES*. 2008. IEEE.
[8] Gkatzikis, L., I. Koutsopoulos, and T. Salonidis, *The role of aggregators in smart grid demand response markets.* IEEE Journal on Selected Areas in Communications, 2013. **31**(7): p. 1247-1257.
[9] *IEEE Adoption of Smart Energy Profile 2.0 Application Protocol Standard.* IEEE Std 2030.5-2013, 2013: p. 1-348.
[10] Uslar, M., et al., *The Common Information Model CIM: IEC 61968/61970 and 62325-A practical introduction to the CIM*. 2012: Springer Science & Business Media.
[11] *IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads.* IEEE Std 2030-2011, 2011: p. 1-126.

Javad Fattahi received the B.Sc. in Electrical Engineering from Isfahan University of Technology in 2003. He received his M.Sc. in 2011 and Ph.D. in 2015 in Mechatronics Engineering (Control and Robotics) from Sharif University of Technology and the University of Ottawa, respectively. Since then, he has been active in the field in distributed control, power electronics, IoT sensors, and embedded computing as a research associate in the Smart Autonomous Grid Edge laboratory (SAGE-Lab) at uOttawa. His research interests are in the areas related to systems control, including embedded computer control, linear/nonlinear systems, and control systems for advanced motion and power electronics applications.

Henry Schriemer received the B.Sc. degree in mathematics, and the Ph.D. degree in physics, from the University of Manitoba, Canada, in 1987 and 1997, respectively. He is currently a Professor in Electrical Engineering at the University of Ottawa where he previously held an NCIT Research Fellowship in Photonics from 2003 to 2005. Prior to this, he spent several years in the photonics industry and earlier held a postdoctoral fellowship in laser physics and nanophotonics at the van der Waals-Zeeman Institute, The Netherlands. He is Associate Director of the uOttawa Sunlab, and leads its SAGE (Smart Autonomous Grid Edge) activities. He has over 25 years' experience in engineered complex systems research and development, and now works extensively with companies to enhance and add value to their technologies. His recent activities have ranged across the photovoltaics landscape, with a present emphasis on the convergence of networks, computing, and technologies needed to realize the smart grid vision. He has authored over 90 peer-reviewed publications.

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

Yue Cao[1], Houbing Song[2], Omprakash Kaiwartya[1], Ao Lei[3], Yue Wang[1] and Ghanim Putrus[1]

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

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

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

[1]{yue.cao; omprakash.kaiwartya; yue5.wang; ghanim.putrus}@northumbria.ac.uk, [2]h.song@ieee.org , [3]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 [37] 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) [38] 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 summarizes 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 [38], fruitful literature works have addressed "charging scheduling" [37], 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 [39][40][41] 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 [39] 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 [40], 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 [41] 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 [42] 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 [43][44][45][46][47][48] 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) [49] 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.

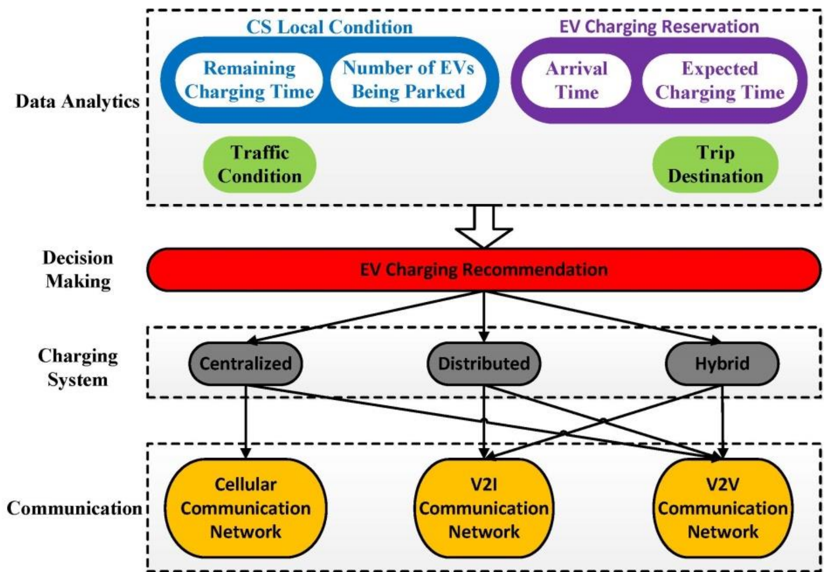


Fig. 1 A Taxonomy on Enabling ICT Technologies for EV Charging Recommendation

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). [43] 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.

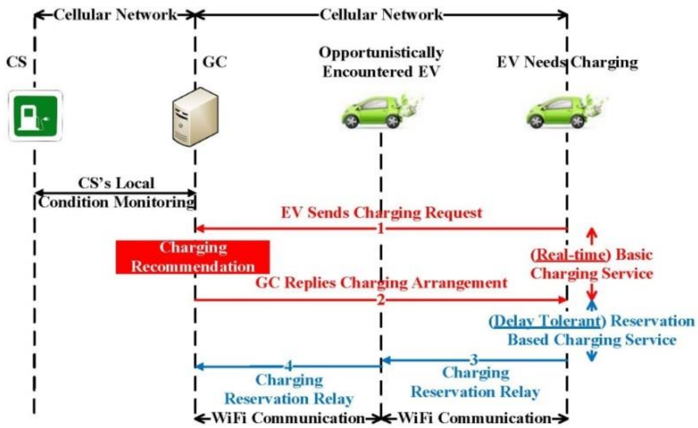


Fig. 2 Signaling Flow of V2V Relaying Charging Reservation

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) [50] based routing protocols provide a significant advantage, by relying more on opportunistic communication to relay EVs' charging reservations.

Envisioning for Internet of EVs, [48] 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 [44] 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 [51] for fast electric taxi charging is shown in Fig. 3.

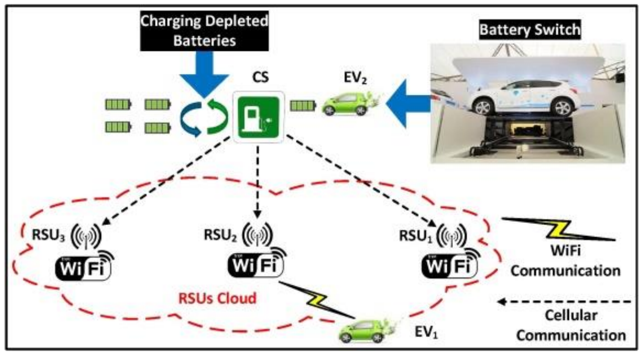


Fig. 3 V2I Enabled Communication Network for Battery Switch

3.2.2 V2V Communication Network Enabled System

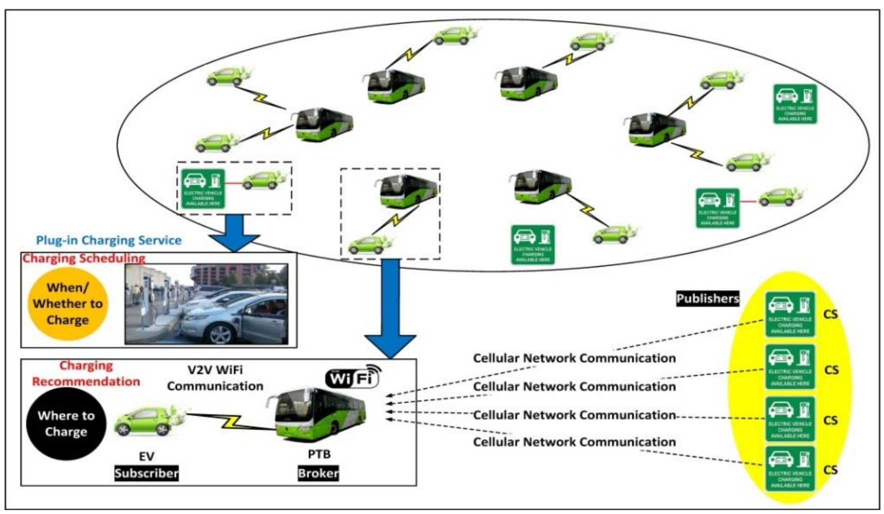


Fig. 4 V2V Enabled Communication Network for Distributed Charging System

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 [45] 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

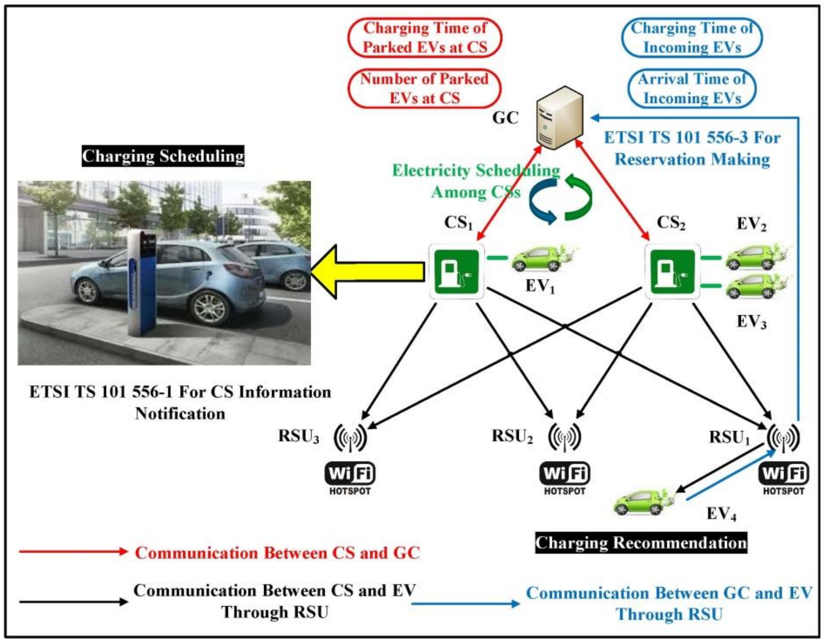


Fig. 5 V2I Enabled Communication Network for Hybrid Charging System

In [46], a hybrid charging system is designed based on V2I communication network, it realizes the application of "ETSI TS 101 556-1" [52] and "ETSI TS 101 556-3" [53] 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

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) [54] 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.

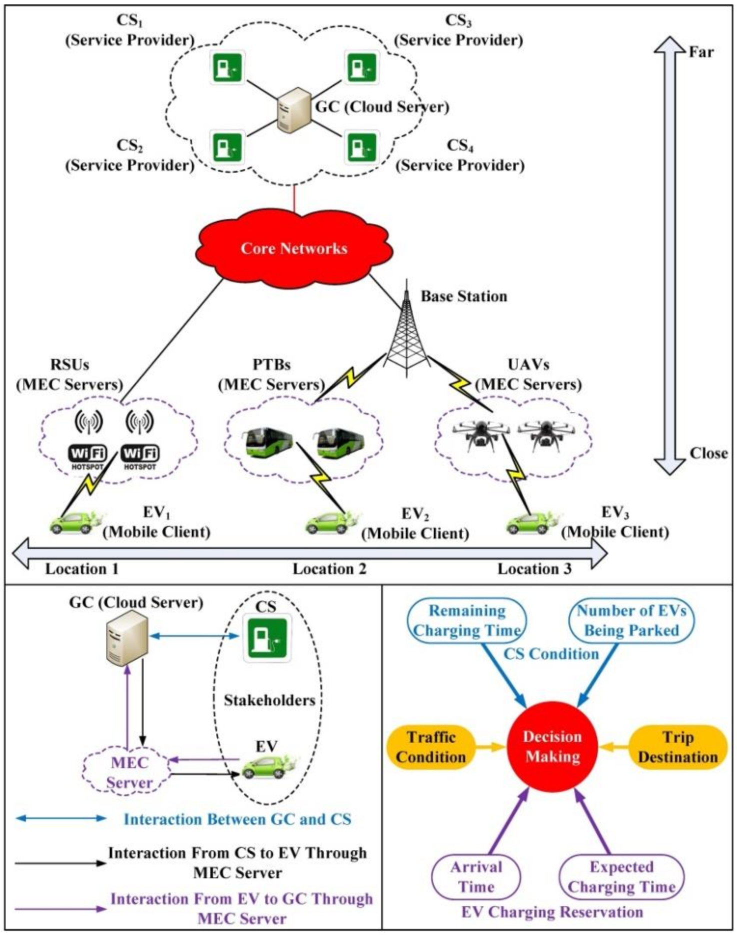


Fig. 6 V2X Enabled Communication Network for Hybrid Charging System

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

[37] 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.

[38] 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.

[39] 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.

[40] 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.

[41] 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.

[42] 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.

[43] 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.

[44] 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.

[45] 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.

[46] 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.

[47] 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)

[48] 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.

[49] 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.

[50] 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.

[51] 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.

[52] "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.

[53] "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.

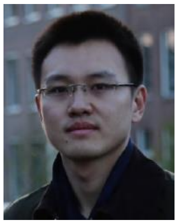
[54] M. T. Beck, M. Werner, S. Feld, and S. Schimper, "Mobile edge computing: A taxonomy," in *Proc. of the Sixth International Conference on Advances in Future Internet*. Citeseer, 2014.

[55] 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.

Big Data for Electric Vehicle-Grid Integration (EVGI) Decision Making

Navjot Singh[1], Mithat Kisacikoglu[2], Melike Erol-Kantarci[1]
[1]School of Electrical Engineering and Computer Science, University of Ottawa, Ottawa, ON
[2]Department of Electrical and Computer Engineering, University of Alabama, Tuscaloosa, AL
nsing060@uottawa.ca, mkisacik@ua.edu, melike.erolkantarci@uottawa.ca

1. Introduction

The internet of things (IoT) is transforming the operation of smart power grid, intelligent transportation, and digital health among many other fields. Integration of Electric Vehicles (EV) to the smart grid has led to a large connected network of things which include EVs, EV charging stations (residential, public, and fast), smart meters. On a larger scale for EV-to-smart city integration, smart traffic lights, intelligent electronic devices (IED), phasor measurement units (PMU) become a part of the network. Adding to this landscape, the emerging self-driving or autonomous electric vehicles (AEV) result in a huge volume of data where the data from vehicles are flowing at high speeds such as in streaming applications. As for as the volume of data and decisions are concerned, the sensors deployed in vehicles provide data that can be used to analyze driving behavior; battery state of charge (SOC) via battery management system (BMS) can be used to infer energy consumption, grid charge management can be implemented based on data from charging stations, and data from other vehicles and the road infrastructure can help in vehicle coordination and platooning. On the other hand, drivers and passengers carry smart devices and wearables which contribute to the data generated by EVs. This data will be continuously moving from vehicles to servers and even vehicle to vehicle. In the case of electric vehicle grid integration (EVGI), EV charging and discharging pattern is tightly coupled with efficient and reliable operation of the smart grid. In that sense, data analytics play a critical role in EVGI related decisions such as long-term decisions including direct current (DC) fast charging (DCFC) station siting and capacity planning, facility development, distribution system planning, and short-term decisions including charge power demand, grid ancillary service support, charging planning/controlling and aggregation of electric vehicles for selling power back to the grid (also known as Vehicle-to-Grid (V2G)). Furthermore, big data from EVs can play a critical role in security of EV infrastructure. Security vulnerabilities in the EV infrastructure can lead to cascaded attacks on the smart grid [1]. Therefore, big data enabled cyber protection decisions are highly demanded.

In our recent article "Big Data Analytics for Electric Vehicle Integration in Green Smart Cities," published in IEEE Communication Magazine in November 2017 [2], we discuss big data and EV related issues in detail. This letter aims to introduce our recent tutorial in the area, bring more insights to the topic and serve as a roadmap for researchers in this area. In this letter, we survey the sources of big data in EVs and their interconnected systems. Then, we survey the literature on data analytics techniques applied to this area. The letter concludes with future directions.

2. Transportation Data in the Era of Electric Vehicles

Nowadays, autonomous self-driving cars whether electric or not, carry hundreds of sensors and they are integrated with smart technologies. Moreover, there is sensory data generated by the road infrastructure with large deployment of connected technologies (i.e. traffic lights, signs, and road cameras). Communication between smart cities and connected EVs/AEVs will multiply the amount of data that is generated and shared, in addition to the data generated by the sensors on the smart phones and wearable devices which are carried by drivers and passengers.

In general, IoT and in particular Internet of Vehicles (IoV) and Internet of Energy (also known as Energy Internet) benefit from cloud services [3] since on-board or on-body devices have limited storage and processing capabilities. Many automobile manufactures have mobile applications by which drivers can check the status of their EVs and remotely monitor their charging. These applications also collect vehicle and trip data. EV data mostly come from on-board electronic control unit (ECU) and BMS. For most charging and discharging decisions, SOC of EV batteries is the primary parameter. BMS logs show SOC info and how an EV battery is performing. Malfunctioning battery cells, heating and cooling details can be observed by these logs. Based on BMS logs, state of health (SOH) information can be obtained and impact of V2G services on battery life can be accurately observed. Besides batteries, battery chargers can provide useful data. According to the charger location, EV battery chargers can be divided into two categories: on-board and off-board. An on-board charger is carried on the EV and can recharge the battery wherever there is an electric outlet. Off-board chargers are usually referred to as charging stations. They generate higher kilowatt transfer and remove weight from vehicle. According to the power flow, the EV battery chargers can be classified as unidirectional or bidirectional. Unidirectional chargers are simple in terms of interconnection and they only support charging. A bidirectional charging system supports both G2V and V2G, and can provide more advanced grid support services that will achieve better vehicle-grid integration. Chargers can generate data related to current drawn from the grid or supplied to the grid and the direction of power flow.

Figure 1 summarizes four main categories of EV data generation sources: battery system, charging system and power grid, on-board charger and EV mobility; that are associated to four example applications: optimized charging, battery consumption prediction, meter data management and EV status tracking. Most of the EV generated data is shared with vendors or grid operators and users do not actively participate in data sharing. However, drivers can also voluntarily share information about their trip, driving patters, charging habits and their preferences. These information may include ranking of convenience of charging stations, malfunctioning stations, traffic on the route, etc.

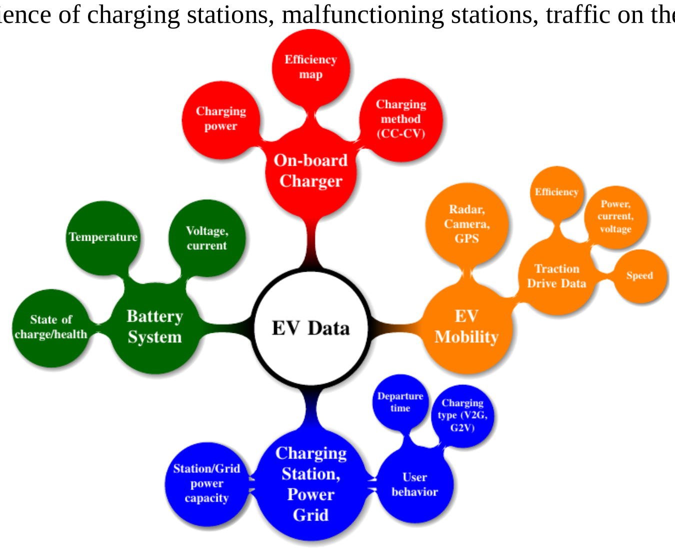


Fig. 1: Data Sources.

3. Big Data in Decision Making

Big data analytics can bring significant insight into decision making regarding where to sit charging stations, when to charge a vehicle, when to use an EV as a supply and so on. In particular, big data is currently being used to estimate driving range which is an efficient way to overcome the range anxiety. Primary factor for installation of charging station is analyzing the charging demand which depends on different factors such as vehicle ownership, road traffic density, distribution of gas stations, etc. According to various case studies, which are using travel patterns of the taxi fleets to understand extend of resources needed, charging station installation locations can be determined with big data analytics. A case study in Beijing considers a data set of 11,880 taxis for a month. Another study in Seattle makes use of 30,000 personal trip records collected from the Puget Sound Regional Council's 2006 household travel survey [4]. For instance, in this study EV parking locations and durations have been estimated using regression methods based on parked-time per vehicle-trip, total vehicle-hours per zone, local jobs, population density, trip attributes and site accessibility.

4. Big Data Tools Used in EV Research

In this section, we summarize several research studies that have used big data tools on EV data.

Hadoop-based optimized charging: Wang et al. [5], have developed a Hadoop based cloud computing platform to process big data in parallel. They used this platform to implement electric vehicle multilevel feedback queue optimization charging model which is a combination of job scheduling optimization and multisource fusion. To accelerate the calculation, MapReduce (MR) parallel algorithm was employed.

Hadoop-based stream data management: In [6] the authors proposed an electric vehicle charging management system for interoperable charging facilities. They implemented a data analysis framework which after retrieving the temporal stream records from the Master Data Management Software (MDMS), uses Hadoop Pig scripts to filter the raw data. In their case, instead of managing the data in a database system, Hadoop efficiently handles the massive amount of stream data. Then the Hadoop Pig script results have been converted to SQL commands to insert them to MySQL. In this way, data is provided for any application either V2G or G2V through the X-DBC (Data Base Connectivity) mechanism.

Hadoop-based battery consumption prediction: In [7] the authors used Hadoop and the R statistical package to process the data of SoC changes of electric vehicles and determined their battery consumption pattern.

NoSQL based EV analytics: Vamshi et. al [8] proposed using NoSQL technology for EV data analytics. Initially the data files are imported into HDFS for Hadoop to use efficiently. Apache HBase is also deployed for providing faster and random reads on data and is scalable to host large tables. Instead of using flat files they use Hadoop to store data and deploy MR jobs for the parallel data processing.

Weka-based EV analytics: In [9], Ranganathan et al. proposed using decision tree algorithms provided in the Weka data mining platform to analyze smart grid and EV data, and form a decision tool for grid operators. The authors used NY Independent System Operators (NYISO) demand data that is publicly available. The proposed decision support system has two phases: data preprocessing and data classification. The data preprocessing stage removes irrelevant data and noise, while classification is used to reach a decision and is based on a decision tree with predefined rules.

5. Conclusion

EV integration requires fast and effective data analytics approaches. There are a few studies in the literature that apply big data analytics tools over EV data sets and use the outcomes in decision making. However more studies are needed on streaming data with a large volume. In addition, security and privacy are still among the open issues. In [10] the authors discuss the blind energy big data attack which uses a replay mechanism that can be implemented without needing the information on power grid topology and transmission line admittances. Therefore, the increased vulnerability of the systems with the availability of big data, as well as robust protection schemes that can be implemented using big data needs to be carefully weighed.

In this letter, we aim to increase interest in this growing area of research. For more detailed information the readers are referred to our recent article "Big Data Analytics for Electric Vehicle Integration in Green Smart Cities", published in IEEE Communication Magazine in November 2017.

Acknowledgement

This research is supported by the U.S. National Science Foundation (NSF) under Grant Number CNS-1647135 and the Natural Sciences and Engineering Research Council of Canada (NSERC) under RGPIN-2017-03995.

References

[1] S. Mousavian, M. Erol-Kantarci, L. Wu, T. Ortmeyer, "A Risk-based Optimization Model for Electric Vehicle Infrastructure Response to Cyber Attacks," accepted for publication in IEEE Transactions on Smart Grid, 2017.

[2] B. Li, M. Kisacikoglu, C. Liu, N. Singh, Melike Erol-Kantarci, "Big Data Analytics for Electric Vehicle Integration in Green Smart Cities", accepted to IEEE Communication Magazine, 2017.

[3] K. Wang; J. Yu; Y. Yu; Y. Qian; D. Zeng; S. Guo; Y. Xiang; J. Wu, "A Survey on Energy Internet: Architecture, Approach, and Emerging Technologies," in IEEE Systems Journal, vol.PP, no.99, pp.1-1, 2017.

[4] T. Chen, K. Kockelman, and M. Khan, "Locating Electric Vehicle Charging Stations: Parking-Based Assignment Method for Seattle, Washington," Transportation Research Record: J. Transportation Research Board, vol. 2385, 2014, pp. 28–36.

[5] Wei W, Minghao A, Naishi C, Xianjun G, Tianjiao P. "Multi-level Feeder Queue Optimization Charging Model of Electric Vehicle and its Implementation of MR Algorithm". International Journal of u-and e-Service, Science and Technology. 2016 Mar 31;9(3):199-208.

[6] Lee J, Park GL. "Electric vehicle charger management system for interoperable charging facilities". Jurnal Teknologi. 2016 Jan 1;78(5-8):117-21.

[7] Lee J, Park GL, Cho Y, Kim S, Jung J. "Spatio-temporal analysis of state-of-charge streams for electric vehicles". In Proceedings of the 14th International Conference on Information Processing in Sensor Networks 2015 Apr 13 (pp. 368-369). ACM.

[8] Bolly V, Springer J, Dietz E. "Using Open Source NoSQL Technologies in Designing Systems for Delivering Electric Vehicle data Analytics". InPaper to be presented at the 121st ASEE Annual Conference, Indianapolis, IN 2014.

[9] P. Ranganathan and K. Nygard, "Smart grid data analytics for decision support," *2011 IEEE Electrical Power and Energy Conference*, Winnipeg, MB, 2011, pp. 315-321.

[10] W. L. Chin, W. Li and H. H. Chen, "Energy Big Data Security Threats in IoT-Based Smart Grid Communications," in IEEE Communications Magazine, vol. 55, no. 10, pp. 70-75, OCTOBER 2017.

Navjot Singh is pursuing his MASC degree at the School of Electrical Engineering and Computer Science at the University of Ottawa. He received his B.Tech degree in computer science and engineering from Punjab Technical University, Punjab, India, in 2016. His research interests include big data, electric vehicles, wireless networks and 5G.

Mithat C. Kisacikoglu received the B.S. degree from Istanbul Technical University, Istanbul, Turkey, in 2005; M.S. degree from the University of South Alabama, Mobile, AL, in 2007; and the Ph.D. degree from the University of Tennessee, Knoxville, TN, in 2013, all in electrical engineering. He joined Hacettepe University, Ankara, Turkey as an Assistant Professor with the Department of Electrical and Electronics Engineering in 2014. He then worked at National Renewable Energy Laboratory, Golden, CO as a research engineer between 2015-2016. He is currently an Assistant Professor in the Electrical and Computer Engineering at University of Alabama, Tuscaloosa, AL. His research interests include electric vehicles (EVs), EV-grid integration, renewable energy sources, and power electronics converters. Dr. Kisacikoglu was the recipient of Post-Doctoral Return Fellowship Award from The Scientific and Technological Research Council of Turkey (TUBITAK) in 2013. He is an Associate Editor of The IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS since 2014. He also serves as the Secretary of the Transportation Systems Committee in IEEE INDUSTRY APPLICATIONS SOCIETY since 2017.

Melike Erol-Kantarci is an assistant professor at the School of Electrical Engineering and Computer Science at the University of Ottawa, ON, Canada. She is the founding director of the Networked Systems and Communications Research (NETCORE) laboratory. She is also a courtesy assistant professor at the Department of Electrical and Computer Engineering at Clarkson University, Potsdam, NY, where she was an assistant professor prior to joining University of Ottawa. She received her Ph.D. and M.Sc. degrees in Computer Engineering from Istanbul Technical University in 2009 and 2004, respectively. During her Ph.D. studies, she was a Fulbright visiting researcher at the Computer Science Department of the University of California Los Angeles (UCLA). She is an editor of the IEEE Communications Letters and IEEE Access. She is the co-editor of the books “Transportation and Power Grid in Smart Cities: Communication Networks and Services” and “Smart Grid: Networking, Data Management, and Business Models”. She is a senior member of the IEEE and the past vice-chair for Women in Engineering (WIE) at the IEEE Ottawa Section. She is currently the vice-chair of Green Smart Grid Communications special interest group of IEEE Technical Committee on Green Communications and Computing. She is also the research group leader for IEEE Smart Grid and Big Data Standardization. Her main research interests are 5G and beyond wireless networks, smart grid, cyber-physical systems, electric vehicles, Internet of Things, big data and wireless sensor networks.

SPECIAL ISSUE ON Multiple Wireless Technologies and IoT in Industry: Applications and Challenges

Guest Editors: Nathalie Mitton, Inria, France

nathalie.mitton@inria.fr

IoT and different wireless technologies are gaining interest and performances in terms of efficiency and reliability. Their use in many industrial applications has been far envisioned. At the dawn of Industry 4.0 and Smart Factories, the IEEE COMSOC MMTC letters wish to share with you the current trends in the use of IoT and diverse wireless technologies in industrial applications, ranging from the benefits to the different challenges raised.
We are very enthusiast to present you this special issue in which leading research groups, report their thoughts and solutions for meeting these challenges.

The first article is proposed by *Xavier Vilajosana* and his team and shares some industrial testimony of the (non)-use of wireless communications in Industry. Based on this assessment, the paper explains the impediments to a wider adoption and proposes some research directions to lift them.

The second article provided by *ICube lab, CNRS / University of Strasbourg* focuses on a standard routing protocol widely used in Industrial wireless networks, e.g. RPL and points out the negative impact of the frequency the self-reconfiguration of one of its parameters.

The third article titled, "*Towards 5G-enable UAV Systems for industrial Infrastructure Inspection"* presents a completely different industrial application in which Internet of Things and wireless communications can come into play, browsing the related benefits and challenges.

The last article proposed by Arizona State University enlarges the scope of IoT in industry by studying the bandwidth allocation in crowded environments such as industrial ones, for bandwidth consuming applications such as image transmission.

While this special issue is far from delivering a complete coverage on this exciting research area, we hope that these letters give the audiences a taste of the main trends and research ways in this area, and provide them an opportunity to explore and collaborate in the related fields. Finally, we would like to thank all the authors for their great contribution and the MMTC E-Letter Board for making this special issue possible.

Nathalie Mitton received the MSc and PhD. degrees in Computer Science from INSA Lyon in 2003 and 2006 respectively. She received her Habilitation à diriger des recherches (HDR) in 2011 from Université Lille 1. She is currently an Inria full researcher since 2006 and from 2012, she is the scientific head of the Inria FUN team which is focused on small computing devices like electronic tags and sensor networks. Her research interests focus on self-organization, energy efficient routing algorithms for wireless sensor networks as well as RFID middlewares. She has published her research in more than 30 international revues and more than 100 international conferences. She is involved in the set up of the FIT IoT-LAB platform (iotlab.info), the FP7 VITAL or H2020 VESSEDIA projects and in several program and organization committees such as Pe-Wasum 2017, VTC 2017&2016, WSCP2017, SWC 2017, WPMC 2017, ICT 2017, Globecom 2017, infocom workshop 2017, AdHocNow 2016&2015, MobiCom 2015, etc. She also supervises several PhD students and engineers.

The Wireless Technology Landscape in the Manufacturing Industry: A Reality Check

Xavier Vilajosana, Cristina Cano, Borja Martinez, Pere Tuset, Joan Melià, Ferran Adelantado
Wireless Networks Research Lab. Universitat Oberta de Catalunya. Catalonia, Spain
{xvilajosana,ccanobs,bmartinezh,peretuset,melia,ferranadelantado}@uoc.edu

1. Introduction

An upcoming industrial IoT revolution, supposedly led by the introduction of embedded sensing and computing, seamless communication and massive data analytics within industrial processes [1], seems unquestionable today. Multiple technologies are being developed, and huge marketing efforts are being made to position solutions in this industrial landscape. However, we have observed that industrial wireless technologies are hardly being adopted by the manufacturing industry. In this article, we try to understand the reasons behind this current lack of wireless technologies adoption by means of conducting visits to the manufacturing industry and interviews with the maintenance and engineering teams in these industries. The manufacturing industry is very diverse and specialized, so we have tried to cover some of the most representative cases: the automotive sector, the pharmaceutical sector (blistering), machine-tool industries (both consumer and aerospace sectors) and robotics. We have analyzed the technology of their machinery, their application requirements and restrictions, and identified a list of obstacles for wireless technology adoption. The most immediate obstacles we have found are the need to strictly follow standards and certifications processes, as well as their prudence. But the less obvious and perhaps even more limiting obstacles are their apparent lack of concern regarding low energy consumption or cost which, in contrast, are believed to be of utmost importance by wireless researchers and practitioners. In this reality-check article, we analyze the causes of this different perception, we identify these obstacles and devise complementary paths to make wireless adoption by the industrial manufacturing sector a reality in the coming years.

2. Analyzed Industries and Observations

We have visited industries in four different sectors to gather real information from actual deployments and use cases. The gathered information has also been compared to the use cases identified by the IETF Detnet WG [2].

2.1 Automotive

Within the automotive industry, there is a large set of specific machinery to manufacture and assemble the different parts of a vehicle. One significant example of such machinery is press lines. The manufacturing of large parts, mainly for vehicle bodywork, requires the use of various presses. Presses are long-lasting machinery with operational lifetimes of more than 50 years. Newest presses today are large distributed systems, composed of thousands of embedded devices that control motors and hydraulic pressure pumps. Communication to the system controller is conducted through Ethernet buses with industrial control protocols, such as Profinet. Legacy machines (some of them from the 60s) use industrial field buses, with proprietary technologies like the legacy Simatic S5 PLC. We have not observed any wireless link in the presses, even in the newest ones (installed in 2017 in the plant). Accessories or newer sensors are rarely added, but in such rare cases, they are provided by the press vendor using the specific machine interfaces, mostly based on Programmable Logic Controllers (PLC) and wired industrial networks.

2.2 Blistering in Pharma

In any pharmaceutical industry, the packaging process is complex and involves large infrastructures and assembly lines. Each line is composed by different chained machines that assemble the pills, control that the blisters are correctly filled and box them. Machines integrate a large number of sensors and cameras (for computer vision control) interfaced by the machine central controller or a remote SCADA system. Hard real-time control happens inside the machine through field buses or deterministic Ethernet. We observed that the pharmaceutical plant is instrumented by an optical fiber-based double industrial Ethernet network to achieve redundancy. During our interviews, wireless technologies were only mentioned as an alternative to have redundant thermostats for the industrial HVAC (Heating, Ventilating and Air Conditioning). Similarly to the automotive industry, accessories are typically provided by the machinery vendors and use common PLC interfaces through wired industrial networks and protocols to achieve interoperability.

2.3 Large Machinery-Tool Manufacturing

Analogously to the automotive sector, the manufacturing of large machines involves complex production lines, typically constituted by custom-made machine-tools and robots that are built in an ad-hoc manner to address one specific task in the production/assembly line. We visited an industry that develops machine-tools to manufacture airplane parts. These machines are large blocks (with a longitude in the order of 50 meters) with articulated arms and transportation platforms operated by hundreds of PLC systems. Communication between subsystems is performed through fiber-optics or deterministic Ethernet networks running industrial communication protocols, such as PROFINET, POWERLINK, EtherCAT or SERCOS. SCADA systems are used in the backend, with the newest ones offered as a cloud service instead of embedded in a given computer. We also visited another industry that manufactures metalforming machinery for the consumer sector. These machines are large distributed systems that bend metal to, for example, manufacture cocking utilities or vehicle rims. Cameras, pressure and temperature sensors are massively used to control the process. All the subsystems are interconnected through Ethernet cables and information is transported with MODBUS over TCP/IP. Real-time controllers use dedicated microcontroller buses such as PCI Express or CAN.

2.4 Industrial Robotics

Industrial robots are automated, programmable and usually articulated. The head or extreme of the arm can be adapted to different applications such as soldering or assembling. We visited a major articulated industrial robot manufacturer and analyzed the most advanced robots under development. They are composed of numerous distributed embedded controllers networked through field buses or industrial Ethernet. They use a large set of sensors and encoders to track movement and position. Motor control loops are handled by different dedicated control units. Hard real-time is handled by on-board buses such as CAN. Wireless communications are not used for the internal communication and control subsystem. In our visit, we found interest in using wireless communication to stream camera images from rotating parts in the extremes of the arm.

3. Identified Obstacles for Wireless Adoption

The most shocking fact of what we have observed is that wireless technologies are not widely adopted by the manufacturing industry nowadays. In this section we discuss the reasons we have identified behind this lack of adoption.

1) Over-dimensioning

We observed that, despite the application requirements imposed in certain subsystems are low, solutions based on fiber-optics providing nanosecond latency are used. This indiscriminate use of ultra-reliable wired technologies, despite their features are not being fully exploited, seems to be the norm. In general, ultra-reliable technologies are used even when not needed. The reasons we infer with respect to this fact are:

I) The *cost of communication* is insignificant compared to the cost of the industrial equipment. When considering large machinery, like a press line, or an aeroplane wing manufacturing machine, the cost of cabling and using the most ultra-reliable communication solution is insignificant compared to the whole machine. So, little concern is given to the cost of communication, which is in clear opposition to the design requirements addressed by researchers and practitioners that consider reduction of cost of utmost importance.

II) *Low power operation* is not of concern. We observed that all devices that connect to, or are part of the machinery or are already powered to a source of energy, removing the need for low power communication.

2) Resistance to change

We have observed a strict resistance to the adoption of new <u>substitute</u> communication technologies. Even when a communication technology fulfills the goal it is usually not changed. The reasons we can guess are:

I) The *cost of ownership* imposes resistance to adopt substitute technologies. When a candidate technology does not provide any perceived advantage to what is used, the effort of getting into it limits its adoption.

II) The *cost of implantation* and/or replacement. Introducing wireless technologies (as any other) require technical interventions that may impact on the production lines or production lifecycles, hence, manufacturers are very prudent and only drive interventions when is strictly needed.

III) *Limited support to legacy industrial standards*. Despite the large efforts conducted by the standardization bodies to interconnect “IoT” wireless devices to the Internet in the last years, industry perceives a lack of support of application-level and transport protocols addressing industrial technologies. The IETF CoAP, MQTT-S and other efforts have addressed the connection of constrained devices to Internet services, but we have seen almost no effort to support industrial transport and application protocols on top of wireless technologies. Industrial SCADA systems expose interfaces based on HTTP, OPC-UA, MODBUS, PROFINET but mostly not CoAP or MQTT yet.

IV) We have observed that when an industry uses a particular technology, and that technology performs as it is required, manufacturers stick to it. Even further, manufacturers stick to particular vendors because they value the service and the confidence that the solution will work in the long term.

3) Wireless performance is perceived to be poor

Despite several standards have emerged to provide reliable wireless communication (e.g PROFINET over 802.11 PCT, WirelessHART. IEEE802.15.4-TSCH, IETF 6TiSCH, DECT-ULE), we have seen them very rarely in the visited industries. Wireless is perceived as a non-reliable technology. We derived the following reasons:

I) Contention-access based technologies such as Zigbee have perhaps influenced the belief that wireless cannot be used for reliable communications.

II) We noted that the usual requirements for the type of control that is required [2] is quite far from the few milliseconds latency that can be guaranteed with deterministic wireless networks [4].

III) It is known that wireless networks performance is, in the best case, similar to an equivalent wired solution performance. The key advantages of wireless are in the operative side since cabling is not needed, however, this is not fully perceived as a key need for most of the use cases as described above.

4) Perception of an immature wireless market

There is a clear perception of quick obsolescence and market fragmentation of wireless technologies. Some of the inferred reasons are:

I) There is a belief that wireless technologies are very fragmented and that there is not a “de-facto” standard that can be adopted with confidence. This can be explained by the perceived youth of the current wireless communication market, where several new standards and proprietary solutions are emerging every year.

II) For the same reasons, there is also the belief that wireless technologies have quicker obsolescence than industrial wired standards. This is perceived as a risk by the industry, considering that machinery has a long operative lifetime, sometimes in the order of 30 years.

5) Environmental barriers

The environmental characteristics of an industrial scenario are quite challenging for wireless communications. Although pioneering studies demonstrate high levels of reliability for WirelessHART and pre-6TiSCH networks in real industrial settings [5], we have observed distrust in wireless technologies. This is specially relevant in large metallic machines or environments where concrete walls confine parts of the machinery.

4. Potential Paths for Wireless Adoption

In this section we devise some potential paths to follow in order to address the obstacles identified before.

1) Understand industrial requirements

Perhaps one of the most surprising identified obstacles for wireless adoption results from the apparent lack of concern for low energy consumption and cost of industrial communication devices, although these two aspects are seen by researchers and wireless practitioners as highly important to guarantee adoption by the industry. Therefore, one of the most important goals is to improve our understanding of their requirements. We believe that without increased communication channels with the industry, the adoption will continue to be just anecdotal.

2) Increase added value

We perceived a lack of appreciation of the value that can provide wireless technologies. We believe that this can be enhanced through the following paths.

Fill the missing gaps today: By identifying unresolved problems or by augmenting existing machinery functionalities, wireless can start building trust and foster adoption. Maintenance departments are key allies for wireless technologies as their deployment dramatically simplifies their task. Addressing support of industrial application and transport standards on top of wireless PHY and MAC technologies may foster adoption.

Integration of wireless in machinery: By working together with the machinery manufacturers we could then guarantee that standard industrial wireless solutions used by the industry do not quickly become obsolete. Integrating industrial wireless solutions in the machines from the vendors they already know strengthens trust, and allows for a reduction the cost of adoption and implantation.

Reduce the cost of ownership: The cost of ownership is a clear factor against change. Further efforts on standardization and transparent solutions to the application are needed. Efforts must be taken to simplify knowledge transfer and formation to the industry. Also by adapting industrial well-established technologies over different wireless technologies so adoption is simplified.

3) Improve the perception about the technology

Since wireless technologies are perceived negatively, and over-dimensioning is the norm, technology perception improvement can be addressed by working on specific use-case deployments. In particular, those that can only be addressed by wireless technologies may be more appropriate. One such example is predictive maintenance of rotors. Features like temperature of the rotor's surface, directly linked to the motor's performance, is currently approximated with thermal cameras. However, embedded temperature sensors powered by battery-less RFID tags or small 6TiSCH networks may reliably predict performance issues, reducing maintenance downtimes and production interruptions. This can help the manufacturing industry to realize the benefits of wireless and create trust on the technology.

4) Strong standardization

Huge efforts are done towards Internet integration (IP-Enabled) of wireless technologies, which may now look on how to support the widely adopted industrial standards over IP (e.g Modbus, Profinet, etc..). For instance, promoting the wireless standards already adopted in other industrial markets or sectors through standardization bodies alliances, recent standards, and consolidating wider specifications covering multiple verticals/sectors, may help to fill the missing gaps and to join industrial requirements. This will provide a vision of continuity of the technology, and hence, reducing the quick obsolescence perception.

5) Study the adequacy of more powerful wireless technologies

It seemed clear until now that low-data rate technologies were well-suited for other industrial scenarios such as metering, infrastructure monitoring, etc. However, to address low-latency control loops, to improve the current negative perception of performance, as well as to address industry preference for reliability via over-provisioning, higher capacity and more reliable wireless technologies compared with the traditional low-power IoT can benefit wireless adoption in a substantial manner.

5. Final Remarks

In this paper, we have presented the results of a reality check of wireless technologies adoption in industrial environments. We have analyzed the use level of these technologies in five different sectors and identified key challenges and needs. We have also identified strategies for the wireless technologies industry to channel these needs and shape future wireless technologies. Ultimately, this should help to materialize the wireless technology adoption in industrial environments, that is taking too long to happen.

Acknowledgements

Work supported by the Spanish Ministry of Economy and the FEDER fund under SINERGIA (TEC2015-71303-R).

References

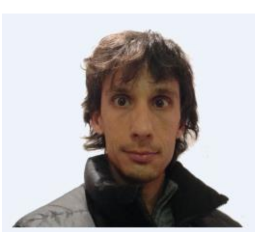
[1] PC Evans, M Annunziata "Industrial internet: Pushing the boundaries of Minds and Machines" General Electric Reports, 2012.

[2] E. Grossman, et. al, "Deterministic Networking Use Cases. IETF Detnet 2017. draft-ietf-detnet-use-cases-13 (Work in progress)

[3] K. Pister et al. "Industrial Routing Requirements in Low-Power and Lossy Networks". RFC5673 IETF 2009

[4] C. B. Schindler, T. Watteyne, X. Vilajosana and K. S. J. Pister, "Implementation and characterization of a multi-hop 6TiSCH network for experimental feedback control of an inverted pendulum," 2017 15th International Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks (WiOpt), Paris, 2017, pp. 1-8. doi: 10.23919/WIOPT.2017.7959925

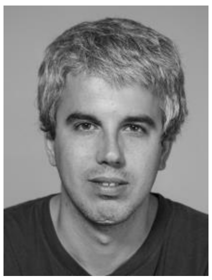
[5] L. Doherty, W. Lindsay and J. Simon, "Channel-Specific Wireless Sensor Network Path Data," 2007 16th International Conference on Computer Communications and Networks, Honolulu, HI, 2007, pp. 89-94. doi: 10.1109/ICCCN.2007.4317802



Dr. Xavier Vilajosana is principal investigator at the WINE research group at UOC and professor at the Computer Science, Telecommunications and Multimedia department. He has been Senior Researcher at the HP R&D Labs and former visiting Professor at the University of California Berkeley. Xavier has been one of the main promoters of low power wireless technologies, co-leading the openwsn.org initiative at UC Berkeley, and promoting the use of low power wireless standards for the emerging Industrial Internet paradigm. Xavier also contributed to the industrialization and introduction of Low Power Wide Area Networks (LPWAN) to urban scenarios. Xavier is author of different Internet Drafts and RFCs at the IETF, as part of his standardization activities for low power industrial networks. Xavier holds more than 40 high impact journal publications. and is author of more than 30

international patents under exploitation. Xavier created two start-up companies.

Dr. Ferran Adelantado (Male): is Associate Professor at the Computer Science, Telecommunications and Multimedia Department and Senior Researcher at the WINE research group at UOC. He holds the degree in Telecommunication Engineering (2001) and the PhD (2007) by the Universitat Politecnica de Catalunya (UPC). He has been involved in several national and International projects in the field of wireless communications. He holds more than 40 high impact publications in international journals and conferences, and has served as TPC in numerous prestigious conferences. His research interests include wireless access networks (4G/5G), small cells, dynamic spectrum access, network sharing, wireless communications protocols and wireless networks virtualization.



Dr. Pere Tuset (Male): is Assistant Professor at the Computer Science, Telecommunications and Multimedia Department of Universitat Oberta de Catalunya (UOC), Senior Researcher at the Wireless Networks (WiNe) research group, and co-founder of OpenMote Technologies. He received the BSc and MSc in Telecommunication Engineering degrees from Universitat Politecnica de Catalunya (UPC) in 2007 and 2011 respectively, and the PhD in Network and Information Technologies from UOC (Universitat Oberta de Catalunya) in 2015. Currently, Pere has published over 10 journal articles and 20 conference papers, and is author of 7 international patents. In 2014 he received the Best Demo Runner-up Award at the prestigious IEEE INFOCOM conference for his demo on Distributed Queuing (DQ) for Active RFID systems. He is IEEE Member since 2012.

Dr. Borja Martinez: is a senior research fellow at the IN3-UOC. He received a BSc in Physics and Electronics Engineering, an MSc in Microelectronics and a PhD in Computer Science from the Universidad Autónoma de Barcelona (UAB), Spain. His research interests include low power techniques for smart wireless devices, energy efficiency and algorithms. From 2005 to 2014, he was Assistant Professor with the Department of Microelectronics and Electronic Systems, UAB.

Dr. Cristina Cano (Female): is a senior research fellow at the WINE research group of the Universitat Oberta de Catalunya (UOC). She has a Ph.D. (2011) on Information, Communication and Audiovisual Media Technologies from the Universitat Pompeu Fabra (UPF). From July 2012 to December 2014, she was a research fellow at the Hamilton Institute in the National University of Ireland, Maynooth (NUIM). Part of this research group is now based in Trinity College Dublin, where she was working from January 2015 to January 2016. Then, in January 2016 she joined the FUN team at Inria-Lille in France. She has published 13 journals and more than 30 conference papers. She is executive editor of the Transactions on Emerging Telecommunications Technologies journal. Her research interests include coexistence of wireless heterogeneous networks, distributed scheduling, performance evaluation and stability analysis.

Dr. Joan Melià-Seguí (Male): PhD (Universitat Oberta de Catalunya, 2011) and MSc in Telecommunications Engineering (Universitat Politècnica de Catalunya, 2005), is a Lecturer at the Estudis de Informàtica, Multimèdia i Telecomunicació, and Researcher at the Internet Interdisciplinary Institute (IN3), both at Universitat Oberta de Catalunya. Before, he has been postdoctoral researcher at Universitat Pompeu Fabra, and the Palo Alto Research Centre (Xerox PARC), California, USA. His research is focused on the Internet of Things, Contextual Intelligence and Security. He has authored or coauthored more than 30 peer-reviewed papers in indexed journals, conferences and workshops, and is coauthor of one patent. He has served as Chair, Programme Committee member, and reviewer for several conferences and journals.

Impact of the Initial Preferred Parent Choice in Wireless Industrial Low-Power Networks

Rodrigo Teles Hermeto, Antoine Gallais and Fabrice Théoleyre
ICube lab, CNRS / University of Strasbourg, Illkirch, France
teleshermeto@unistra.fr, gallais@unistra.fr, theoleyre@unistra.fr

1. Introduction

The Internet of Things has emerged in the last years as a concept that leads to a wireless Internet that connects a myriad of smart systems, from temperature sensors, HVAC systems, to intrusion detectors [1]. All these objects are expected to be deployed in homes, warehouses, streets, or amusement parks.Industry 4.0 is currently an emerging approach, aiming to re-use the IoT concepts in the automation world. The so-called Industrial Internet of Things (IIoT) relies on wireless technologies that are able to provide a high Quality of Service (QoS) for a plethora of industrial applications such as vehicle automation, smart grid, automotive industry or airport logistics. All those applications share similar network performance requirements regarding low-latency and high network reliability.

To provide Quality of Service (QoS) for industrial-like wireless networks, the IEEE 802.15.4-2015 standard was published in 2016 [2]. Time-Slotted Channel Hoping (TSCH) is among the Medium Access Control (MAC) schemes defined in this standard, and targets specifically the low-power, deterministic and reliable wireless industrial networks. TSCH relies on a strict schedule of the transmissions such that each application has enough transmission opportunities while avoiding transmission collisions. When a node is not involved in a transmission or reception, it can safely switch its radio interface off to save energy.

To construct an accurate schedule, the network needs to select the best route(s) for each flow, and to allocate enough transmission opportunities to each node along the path to the sink. Estimating the link quality is consequently of prime interest: Selecting a suboptimal preferred parent implies that many packets have to be retransmitted to be correctly received by the next hop. The routing topology is in other words inefficient and the incriminated nodes may quickly run out of energy. Iova *et al.* [3] highlighted the presence of oscillations in RPL, with many parent changes when using a dynamic link quality metric.

In this letter, we propose to focus on the initial parent choice when a node has to join the network. We share here our experimental characterization, which focuses on the convergence phase.

2. Convergence of RPL when using a default initial metric

Let us consider the topology depicted in Figure 1. In this letter, we propose to focus on the initial parent choice when a node has to join the network. We share here our experimental characterization, which focuses on the convergence phase.

We assume that RPL is used for routing [4]. Let us consider that RPL uses the ETX metric (i.e. average number of transmissions before receiving an acknowledgment) to select the best routes. RPL relies on an objective function to translate a link metric into a *rank*, denoting the virtual distance between the node and the border router. To use the best routes, a node selects as preferred parent its lowest ranked neighbor [4]. The ranks of nodes in its vicinity are derived from the respective estimated quality of the links with these nodes. Unfortunately, measuring the ratio of packet errors requires to exchange first some data packets. Thus, an initial default link quality may be associated with the inactive neighbors. While the 6TiSCH-minimal draft [5] does not

recommend any default ETX value for inactive neighbors, the OpenWSN[1] implementation uses a fixed default link cost equal to 4, thus assuming that the ETX toward an inactive neighbor is 4.
Let consider the Figure 1, with a multihop topology of 6 nodes, including the sink. Each node (*N*) computes its rank based on the rank of its preferred parent (*P*), and its link quality:

$$rank(N) = rank(P) + \text{MinHopRankIncrease} * \text{ETX}(\text{N} \rightarrow \text{P})$$

with `MinHopRankIncrease` being a constant (by default equal to 256), and (ETX(N→P)) denotes the ETX metric from *N* to *P*.
If a default ETX value is used when a link is unprobed. Thus, the node *N* selects as preferred parent its neighbor with the lowest rank, i.e. the node *A*. After the association, the link (N,A) is used, and the link quality estimation is refined, with the correct ETX value: its rank is finally updated (1537). Since the node *B* provides now a lower rank with default ETX value (4*256+260<1537), *N* changes its preferred parent to *B* (which will give a lower rank using the default value 1284). We can note that the node *N* probes iteratively each of its neighbors as preferred parent.
Inversely, *N* will not select *C* or *D* as parent although they provide a better path to the border router. Indeed, their rank with the default value would be 1304 and 1324 respectively. Unfortunately, the rank of *B* (with its actual ETX) is 1028, strictly inferior to the default rank of the other possible parents. A too large ETX default value for inactive neighbors prevents to select the best parents eventually.

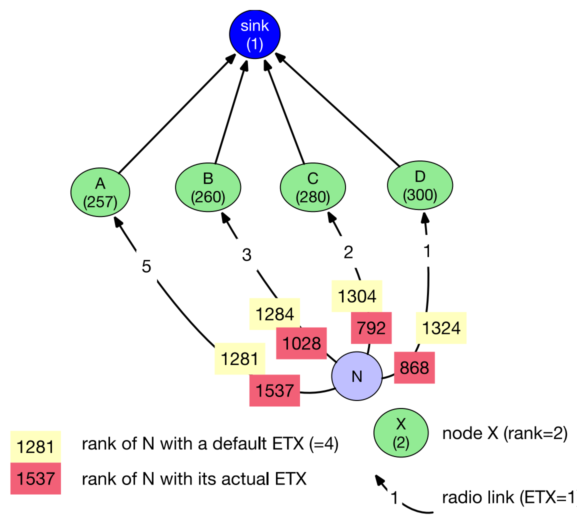


Figure 2: Convergence of the preferred parent choice when using a default ETX value

The problem becomes even trickier to handle with temporal variations, very common for this kind of scenario [6]. For inactive neighbors, the link metric was evaluated a long time ago and does not reflect the current quality. De facto, these neighbors will never be considered again to serve as preferred parent, except if the current one crashes or its link quality becomes very bad (i.e. ETX > 4). For higher network densities, a node may limit the number of neighbors to be included in its neighbors table. In such scenarios, the node would exclude periodically from its table bad neighbors or even nodes that have stayed a long time without communicating. Later, they might be added back with the default link cost until they are probed again. With this inclusion/removal, a node may consider again a bad neighbor when a parent changing is required.

3. Initial Link Quality Estimation with a Reservation Based MAC layer

[1] http://www.openwsn.org

IEEE 802.15.4-2015-TSCH requires a strict schedule of the transmissions. Each cell is identified by its timeslot and channel offset, and is allocated to a set of transmitters. During a shared cell, several transmitters can transmit using a backoff value to regulate the contention. Typically, all the nodes have to stay awake during a shared cell so that a broadcast packet is received by all the nodes with a single radio transmission. Inversely, dedicated cells are contention free, and are allocated to a set of transmitters and receivers which do not mutually interfere.

When executed on top of the IEEE 802.15.4-2015-TSCH, a node has consequently to reserve an amount of transmissions opportunities (*cells*) after having selected its preferred parent. Reserving a set of cells in the scheduling matrix allows the node to transmit its data packets in a contention free manner. However, estimating the link quality for inactive neighbors is particularly challenging. Reserving some contention-free cells for probing each neighbor would provide a very accurate link quality estimation, but would also waste a large amount of radio resource. Inversely, the probes may be broadcasted [7], with transmissions being scheduled in the cells dedicated to broadcast (with contention). Unfortunately, the collisions may distort the estimation.

Moreover, changing the preferred parent over a reservation-based MAC layer is very expensive. A node has to *reinstall* a new set of cells for its new parent. Meanwhile, the data packets use the shared cells, prone to collisions. Thus, routing instabilities negatively impact both the reliability and the overhead.

For this purpose, we used the FIT IoT-Lab[2] testbed of Strasbourg to measure the number of preferred parent changes, and the reliability before the network converges. We used the OpenWSN[1] stack, which implements both IEEE802.15.4-TSCH and RPL protocols. We selected 31 nodes to highlight the instability which arises even in small-scale topologies.

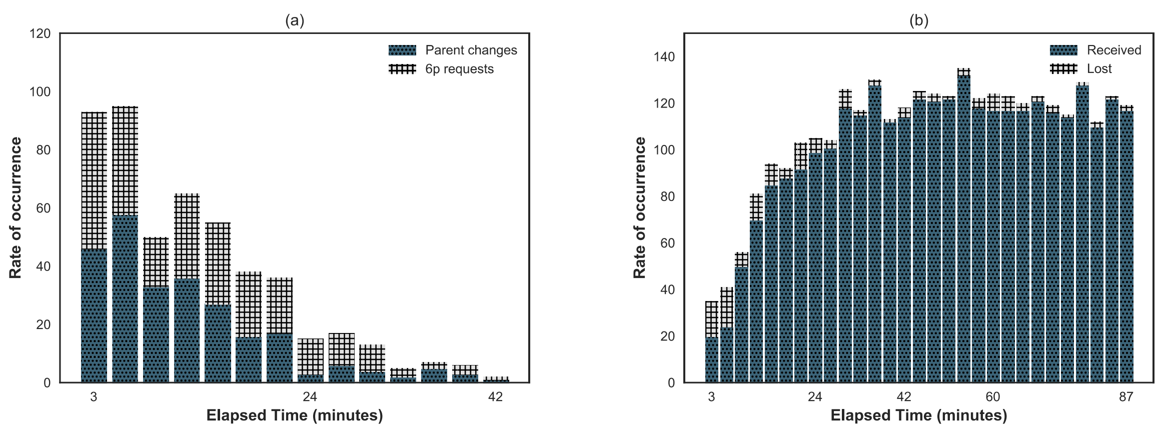


Figure 3 – (a) Number of parent changes/6p commands and (b) the distribution of packet losses during the convergence.

Figure 2(a) exhibits this instability during the convergence phase. We measured the number of parent changes and the number of requests generated by the 6P protocol to modify the schedule. They denote the convergence of the stack. We can observe a high frequency of parent changes and 6P requests. The nodes switch their preferred parents even if the link quality estimation has varied slightly. Because at first a node does not know the link quality to an inactive neighbor, it uses the default link cost. Then, nodes will keep changing their preferred parent until they find a neighbor that fulfills the reliability requirement (i.e. ETX $\leq$ 4). In addition, the instability also affects the Packet Delivery Rate as shown in Figure 2(b). The proportion of lost packets is much

[2] https://www.iot-lab.info/

higher during the convergence phase, as the nodes 'blindly' select parents using the default link quality value. The packets are even dropped because the node has no transmission opportunity toward its preferred parent. Using a hysteresis function [8] would reduce the number of parent changes, but at the price of using very suboptimal parents.

4. Conclusion

In this paper, we highlighted the impact of the default link quality metric for non-probed links on the routing convergence. Changing several times its preferred parent is particularly expensive in TSCH: new transmission opportunities have to be reserved in the schedule, requiring many control packets. Besides, many data packets may be dropped before the new cells are reserved. Our experiments highlighted the need of estimating accurately the link quality **before** attaching to a preferred parent. Using initially a default link quality is suboptimal, and leads to several parent changes. A more accurate passive link quality estimation would be very beneficial in this situation.

References

[1] L. Atzori, A. Iera and G. Morabito, "The internet of things: A survey," *Computer networks,* vol. 54, pp. 2787-2805, 2010.

[2] Std 802.15.4-2015 (Revision of IEEE Std 802.15.4-2, *Low-Rate Wireless Personal Area Networks (LR-WPANs),* IEEE, 2016.

[3] O. Iova, F. Theoleyre and T. Noel, "Stability and efficiency of RPL under realistic conditions in Wireless Sensor Networks.," in *PIMRC*, 2013.

[4] T. Winter and et al., *RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks,* IETF, 2012.

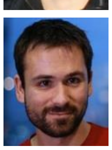
[5] X.Vilajosana and et al., *Minimal 6TiSCH Configuration,* 2017.

[6] X. Ding, G. Sun, G. Yang and X. Shang, "Link Investigation of IEEE 802.15. 4 Wireless Sensor Networks in Forests," *MDPI Sensors,* vol. 16, p. 987, 2016.

[7] E. Ancillotti, R. Bruno, M. Conti, E. Mingozzi and C. Vallati, "Trickle-L2: Lightweight link quality estimation through Trickle in RPL networks," in *IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks*, 2014.

[8] O. Gnawali and P. Levis, *The Minimum Rank with Hysteresis Objective Function,* IETF, 2012.

Rodrigo Teles Hermeto is a PhD student at University of Strasbourg (France). He holds a master degree from Federal University of Ceará (Brazil). His research interests include the Industrial Internet of Things, MAC layer for wireless networks and Testbeds for the Internet of Things.



Antoine Gallais is an associate professor at University of Strasbourg since 2008. He received a PhD from the University of Lille, France (2007), and a HDR habilitation from the University of Strasbourg (2017). His main research interests lie in the areas of wireless sensor and mobile ad hoc networking, mobility management and performance evaluation.

Fabrice Théoleyre is a full researcher at CNRS and University of Strasbourg, France. He received a PhD from INSA of Lyon (2006), and a HDR habilitation (2014) from the University of Strasbourg. He is a senior IEEE member. His research interests comprise wireless networking, with a focus on the Industrial Internet of Things with strict guarantees.

Towards 5G-enabled UAV Systems for Industrial Infrastructure Inspection

Milan Erdelj and Sara Grbčić
Sorbonne Universités, France
Université de Technologie de Compiègne
CNRS UMR 7253 Heudiasyc
milan.erdelj@utc.fr, sara.grbcic@utc.fr

This article envisions the possibility of a 5G-enabled UAV system applied in the industrial infrastructure inspection, and discusses about research challenges and open issues with regard to its practical implementation.

1. Introduction

The wireless communication technologies became an interesting choice for different areas of industrial automation, due to their increased deployment time and higher mobility. In the context of an emerging variety of device hardware and available communication technologies, the 5G cellular communications are being considered as a promising technology and a potential key driver towards the large-scale adoption of future industrial systems. In particular, Unmanned Aerial Vehicles (UAVs) and UAV systems, coupled with a 5G communication means, are already considered as a promising technology for different fields of application, ranging from automated disaster management to automated industrial inspection.

In this article, we envision a 5G-enabled UAV system for industrial infrastructure inspection, and describe its main components. Furthermore, we point out challenges of such a system in terms of UAV precise positioning and localization, creating and maintaining the information relay network, UAV physical constraints and failure handling, automated network maintenance and UAV charging, communication security and robustness.

In the remainder of this work, current wireless technologies used in industrial applications are described in Section 2, the impact of 5G network on Internet of Things (IoT) and industry is discussed in Section 3, while recent advances in UAV technology for infrastructural inspection are provided in Section 4. Challenges and open issues within 5G enabled UAV systems are identified in Section 5 and the conclusion is drawn in Section 6.

2. Wireless Technologies for Industrial Applications

Rapid advances in wireless technologies applied to the domain of consumer electronics, have paved the way towards their implementation in the industrial context as well. Lower wireless infrastructure cost in comparison to its wired counterpart, together with the higher mobility and increased deployment time, make the wireless communication technologies an interesting choice for different areas of industrial automation. Aside the benefits that wireless technologies offer, most of the industrial applications require tight constraints in terms of real-time operation and reliability, that are hard to meet due to the characteristics of the wireless communication medium. Challenges regarding communication issues with wireless technologies in industrial environments are discussed in [10].

Taking account of the real-time operation, reliability and security constraints of industrial processes, current industrial systems leverage different wired and wireless communication technologies in different applications ranging from Smart Grids [12] to the Internet of Things (IoT) [11]. IoT in particular represents a promising future building block for industrial applications by federating most of the recent technological advances in sensor devices, tracking technology, low-range wireless and cellular communications.

An interested reader can refer to the selection of research areas in the field of protocol and system design for industrial communications, is presented in [9]. Furthermore, a survey of the latest trends in the communication domain for distributed industrial systems, that emphasize the important issues such as dependability and standardization, is provided in [2].

3. 5G for IoT and Industry

The mobile broadband network that is constantly evolving, providing new services, several times higher data rates and broad coverage, has arrived up to its 5th generation. Not only focusing on the faster data rates, 5G network also addresses new issues regarding the energy efficiency, support for new and emerging devices, communication reliability, network congestion and lower service cost. In essence, it will rely on the Software Defined Networking (SDN) paradigm, allowing on-the-fly, remote and autonomous network reconfiguration, thus providing higher Quality of Service for end users.

Evolving in parallel with 5G, the concept of IoT gained more traction with a large variety of low-power and low-cost devices that emerged in recent years, together with a variety of implemented supporting communication technologies. This variety of device hardware and available communication technologies impedes the movement towards a unified and ubiquitous communication technology that could address the communication constraints in an industrial environment. Nevertheless, novel industrial scenarios rely on adaptive manufacturing, real-time logistics, autonomous transportation, automated infrastructural inspection, and require a seamless and reliable communication among all of the industrial sub-systems.

In this context, the 5G cellular communications are being considered as a promising technology and a potential key driver towards the large-scale adoption of a future IoT. The analysis of the potential of the 5G technology in the IoT context in presented in [7], where authors also illustrate the potential business shifts that an IoT approach coupled with 5G could cause.

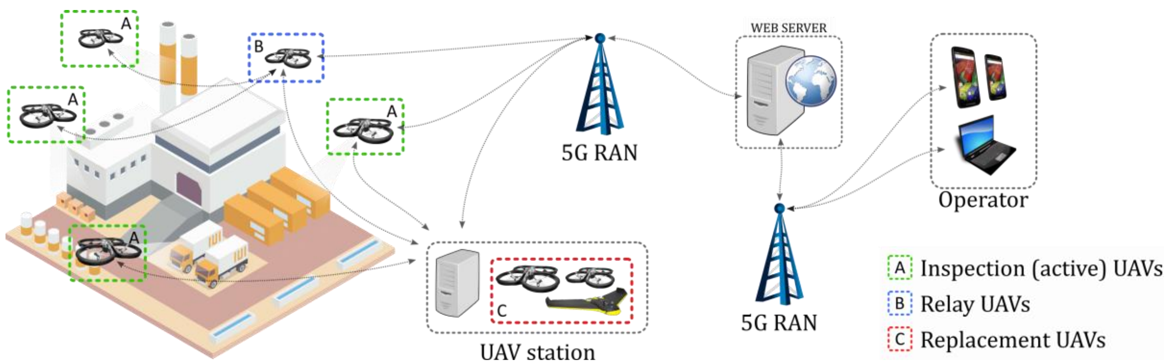


Figure 1. 5G-enabled UAV system for industrial infrastructure inspection.

A detailed survey on the 5G cellular network architecture, together with more information about some of the key emerging technologies, can be found in [3]. In their work, authors propose a general 5G cellular network architecture that integrates small cell access points, network cloud, device-to-device communications and IoT into one all-encompassing system. Similarly, in [5], authors propose a concept of an intelligent cross-domain 5G network management system relying on the technological enablers such as cognitive methods and virtualization techniques for joint management of mobile cellular and industrial networks.

4. UAVs for Industrial Infrastructure Inspection

Since their conception, most of the robotic technologies have been used in all the industrial segments, notably for the purposes of monitoring, inspection, maintenance and reparation of an infrastructure. The wide adoption of these robotic technologies lies in the possibility of automated tasks that are considered to be dull or dangerous, but also on the possibility to greatly reduce the operational cost and increase the speed of a production cycle. At the beginning, a robotic manipulator was piloted remotely by a skilled operator, however, recently the robots gain more and more cognitive autonomy that allows for an industrial process to be completely automated and optimized. A review of robotic solutions applied in the onshore oil and gas industry, mainly focused on the in-pipe inspection robots, tank inspection robots, wireless sensor networks (WSN) and unmanned aerial vehicles (UAV), is presented in [8].

In particular, UAVs and UAV systems are already considered as a promising technology in different fields, ranging from automated disaster management [1] to automated industrial inspection [4, 6]. In the example of low-cost, fast, and safe power line inspection, that would increase the quality of power delivery, an automated UAV inspection is discussed in [4]. Similarly, in [6], authors present a small-scale Unmanned Aerial System (UAS) dedicated to infrastructural inspection in GPS-denied indoor industrial environment. The paper shows that it is possible to rely on a lightweight vision-aided inertial navigation system in order to obtain a precise localization information needed for a precise indoor inspection.

In this article, we envision a 5G controlled UAV system for industrial infrastructure inspection (Figure 1).

Aforementioned communication issues rising from the plethora of different communication solutions could all be merged into all encompassing 5G communication system that would provide the communication among all the components of the system, thus interconnecting remote operator with a particular UAV doing the inspection. The UAV system would include a pre-deployed UAV stations (that could be fixed or mobile), and that an operator could remotely access through a dedicated control station. As shown in Figure 1, UAVs in the system could have multiple roles: infrastructure inspection role (which is their main role), replacement role (in order to replace the operational UAVs with drained battery), and communication relay role. Indeed, UAVs not only survey the affected area but also assist in establishing vital wireless communication links between the UAV stations and nearest available communication infrastructure.

This kind of architecture allows an increased reliability and inspection speed since it allows the use of multiple UAVs in the inspection role, and provides an operator with a continuous remote inspection service by running an automated UAV replacement and an information handover algorithm. The possibility to relocate the visual information processing on a dedicated web server provides the complete system and thus the system operator/user with a greater power in terms of infrastructure inspection speed, automated infrastructural failure detection and automated infrastructure status report. The arrival of the 5G network with its ubiquity, dedicated network slicing, connection reliability and increased information throughput, promises greater expansion of proposed UAV systems, not only in the field of infrastructural inspection, but also in other industry segments.

5. Challenges and Open Issues

Involving UAVs and UAV systems in industrial infrastructure inspection arises several communication and control related research challenges, as described below.

UAV precise positioning and localization. Although numerous research and development efforts rely on the use of global positioning systems for UAV localization, the particular nature of infrastructural inspection requires high precision localization information in both indoor and outdoor environments, that is not easily achievable. Given the high precision requirements for the structural inspection, hybrid approaches that integrate visual odometry, global positioning system and inertial sensors measurements, should be employed. Furthermore, in the particular context of the UAV systems composed of several UAV executing the inspection mission simultaneously, a simultaneous localization and mapping techniques relying on the localization information exchange among the UAVs could greatly increase the positioning and localization precision.

Creating and maintaining the information relay network. The information relaying network formed by the UAVs is completely aerial and must have a high level of resilience towards wireless link outages owing to motion-related changes or energy-level changes among the UAVs. The creation and maintenance of an ad-hoc information relay network is usually a two stage process: an initial round of centralized determination of optimal relay points that connect the other parts of the UAV system to the nearest RAN, followed by a round of de-centralized correction during the deployment.

UAV physical constraints and failure handling. One of the most important constraints imposed on the use of UAVs in any area is their resistance to weather conditions. It is important to focus on the development of specialized hardware suitable for industrial environments, as well as control algorithms that could improve the collective behavior and agility of a UAV system, due to the possible harsh conditions in which the proposed UAV system should be able to perform. Although the envisioned system is designed to be automated up to the point of executing the infrastructural inspection automatically in a scheduled periods of time, in order to ensure the fail-safe operation of the overall system, the operation of the UAVs and the UAV station should be supervised by a human operator present on the spot. The human supervisory component in the system has the task of resetting or stopping the UAVs by engaging the kill-switch, or by manually overriding the remote UAV control. Once the system proved to be feasible in practice, more advanced automated failure handling procedures are to be envisioned and implemented.

Automated network maintenance and UAV charging. Applicable to all the industrial use cases, battery-powered UAVs may need to intermittently dissociate from their inspection mission and the information relay network in order to recharge. Duty cycling these UAVs, i.e., selecting their alternating operational and charging durations, requires careful optimization formulations so that the relay path is always connected, an adequate level of service is provided to the users, and the downtime of each UAV is minimized. Several interesting problems exist in this space, including: (i) performing optimal handoffs between the roles of surveying, last-mile communication with users, and data relaying, (ii) choosing the charging duration, i.e., making tradeoff decisions on whether charging instants should be proactive, even if their battery is not completely depleted, (iii) optimizing the number of hops by building accurate 3-D channel models for various weather conditions and land topologies. The location of charging points as well as the energy transfer methods must be carefully optimized as this impacts the duration of active service. Magnetic-induction based charging plates installed on the supporting mobile or fixed UAV stations is one feasible option, which allows the UAVs to land and re-charge without manual intervention.

Communication security and robustness. In order to provide a robust UAV network control and an uninterrupted information flow towards an end-user, emphasis must be placed on the communication security. Malicious attacks are closely related to the UAV network in operation, where robust communication protocols play the role of utmost importance.

6. Conclusion

In this article, we envisioned a 5G-enabled UAV system for industrial infrastructure inspection, and described its main components. Furthermore, we pointed out the challenges of such a system in terms of UAV precise positioning and localization, creating and maintaining the information relay network, UAV physical constraints and failure handling, automated network maintenance and UAV charging, communication security and robustness. The arrival of the 5G network with its ubiquity, dedicated network slicing, connection reliability and increased information throughput, promises greater expansion of 5G-enabled UAV systems, not only in the field of infrastructural inspection, but also in other industry segments.

References

[1] Milan Erdelj, Enrico Natalizio, Kaushik R. Chowdhury, and Ian F. Akyildiz. Help From the Sky: Leveraging UAVs for Disaster Management. IEEE Pervasive Computing Special Issue on Drones, 16(1):24–32, 2017.
[2] Piotr Gaj. Jürgen Jasperneite, and Max Felser. Computer Communication Within Industrial Distributed Environment – A Survey. IEEE Transactions on Industrial Informatics, 9(1):182–189, 2013.
[3] Akhil Gupta and Rakesh Kumar Jha. A Survey of 5G Network: Architecture and Emerging Technologies. IEEE Access, 3:1206–1232, 2015.
[4] Jaka Katrasnik, Franjo Pernus, and Bostjan Likar. A Survey of Mobile Robots for Distribution Power Line Inspection. IEEE Transactions on Power Delivery, 25(1):485–493, 2010.
[5] Christian Mannweiler, Lars Christoph Schmelz, Simon Lohmüller, and Bernhard Bauer. Cross-Domain 5G Network Management for Seamless Industrial Communications. In Network Operations and Management Symposium (NOMS), 2016 IEEE/IFIP, April 2016.
[6] Janosch Nikolic, Michael Burri, Joern Rehder, Stefan Leutenegger, Christoph Huerzeler, and Roland Siegwart. A UAV System for Inspection of Industrial Facilities. In Aerospace Conference, 2013 IEEE, March 2013.
[7] Maria Rita Palattella, Mischa Dohler, Alfredo Grieco, Gianluca Rizzo, Johan Torsner, Thomas Engel, and Latif Ladid. Internet of Things in the 5G Era: Enablers, Architecture, and Business Models. IEEE Journal on Selected Areas in Communications, 34(3):510–527, 2016.
[8] Amit Shukla and Hamad Karki. Application of Robotics in Onshore Oil and Gas Industry – A Review Part I. Robotics and Autonomous Systems, 75(Part B):490–507, 2016.
[9] Andreas Willig. Recent and Emerging Topics in Wireless Industrial Communications: A Selection. IEEE Transactions on Industrial Informatics, 4(2):102–124, 2008.
[10] Andreas Willig, Kirsten Matheus, and Adam Wolisz. Wireless Technology in Industrial Networks. Proceedings of the IEEE, 93(6):1130–1151, 2005.
[11] Li Da Xu, Wu He, and Shancang Li. Internet of Things in Industries: A Survey. IEEE Transactions on Industrial Informatics, 10(4):2233–2243, 2014.
[12] Ye Yan, Yi Qian, Hamid Sharif, and David Tipper. A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges. IEEE Communications Surveys & Tutorials, 15(1):5–20, 2013.

Milan Erdelj, Ph.D. is a postdoctoral research fellow at the Heudiasyc Laboratory of Université de Technologie de Compiègne (Sorbonne Universités, France). His research interests are in distributed control and communication systems for wireless sensor and robot networks. Erdelj received his PhD in computer science from the University Lille 1, France. Contact him at milan.erdelj@utc.fr.

Sara Grbčić is a Ph.D. student in the field of Technical Mechanics at the Roberval Laboratory of Université de Technologie de Compiègne (Sorbonne Universités, France). Her research interests are the finite element analysis of a micropolar continuum and structural analysis in offshore industry. Grbčić received her MSc degree in civil engineering from the University of Rijeka, Croatia. Contact her at sara.grbcic@utc.fr.

User Satisfaction-Driven Bandwidth Allocation for Image Transmission in a Crowded Environment

Sandipan Choudhuri1, Kaustav Basu2 and Arunabha Sen3 School of Computing, Informatics and Decision Systems Engineering at Arizona State University, Tempe, AZ 85281
{1s.choudhuri, 2kaustav.basu, 3asen}@asu.edu

1. Introduction

We have moved on from the days when social media were dominated by texts; the popular social networking enterprises certainly have changed over the years, and their profound usage of digital images will continue to increase as time progresses. With the advent of new technologies, mobile phone image quality has made considerable progress. Consequently, the digital images produced by them occupy larger storage space. Due to these large sizes, images take larger bandwidth and more time for upload or download through the Internet, thus making it inconvenient for file sharing, especially in crowded environments. To combat this problem, in this paper we lay out a proposal for a user satisfaction driven bandwidth allocation scheme for image transmission in a crowded environment. The crowded environment that we have in mind includes among others, large indoor/outdoor concerts, soccer/football games and political rallies. A large number of individuals attend such events and a significant portion of them take images of the happenings in the arena with their cell phones and transmit them to their friends off the arena using apps such as Whatsapp or post them on Facebook. The bandwidth available in the events arena is usually constrained by the limited number of gateways to carry the data traffic from the arena to the external world. The users also expect that the transmitted images are delivered to their destination or posted in platforms, such as Facebook, in real time. Failure of the network service provider to ensure this requirement causes user dissatisfaction, which the network service provider clearly wants to avoid. We argue that *user satisfaction* is a function of the *received image quality* and the *delay* in receiving the image. The user satisfaction will be high if the received image is of high quality and arrived at the intended destination after a small delay. The image quality in turn depends on the *image size* ($x \times y$ inches) and *image resolution* (z dpi) and a third parameter referred to as the *saliency concordance metric,* which is explained in detail in the section IV. The image *file size* is given by the product of the image size and the image resolution. Higher image quality can be obtained by having large image size and/or high image resolution. However, high image quality also implies large image file size. If the bandwidth allocated to a user by the network service provider is fixed, then the delay encountered by the user will also increase with increase in the image file size. Thus, the parameters, image quality and delay, essentially are antagonistic with respect to each other in their role in improving *user satisfaction*. User satisfaction is not only a function of image quality and delay but also a function of the economic aspect of the service provided by the operator (service charges). However, for the purpose of this study, we focus primarily on the technical component of the user satisfaction (image quality and delay) instead of the economic component.

The network service provider (NSP) would like *maximize* the number of satisfied customers. We assume that each customer C_i, $1 \leq i \leq n$ has a *customer satisfaction threshold* τ_i, $1 \leq i \leq n$. However, due to limited *radio resources* (frequency spectrum, bandwidth) available to the NSP, it may not be possible for the NSP to provide services at a level that will satisfy all the customers. In such a scenario, the NSP has to carefully develop a *policy* to serve the customers so that *overall user dissatisfaction* is *minimized* or *overall user satisfaction* is *maximized*.

User-satisfaction-based bandwidth allocation schemes in wireless environment have been studied in [1, 10, 11, 12, 14]. Among these studies, the one that comes closest to the problem being discussed in this paper is [10]. However, there exists significant differences between the approach taken in [10] and the one proposed in this paper. In many studies on user-satisfaction-based resource allocation problem (including [10]), user-satisfaction is modeled over logarithmic or exponential functions. We propose a machine-learning-based approach to compute the user-satisfaction function. We plan to develop this function based on customer survey data that includes the *quality of image*, *delay encountered* and corresponding *user-satisfaction index*. The user-satisfaction function used in [10] does not take into account any *semantic information from the image being transmitted*. A major difference between our approach and the one proposed in [10] is that we incorporate *saliency-based information* in our image compression framework.

The authors in [1] study *satisfaction maximization problem* for both *real time* and *non-real time* services. They use two different approaches, one *heuristic* and the other *utility based* to find solutions to the satisfaction maximization problem in real time and non-real time environments. As correctly noted in [1], one of the most important aspect of NRT service is *information integrity*, i.e., information loss is *unacceptable*. However, the application scenario that's under consideration in this paper, i.e., image transmission in a crowded environment, a certain amount of information loss (either through image compression or any other means) may be *acceptable*, as long as it doesn't significantly degrade the image quality. A number of techniques are currently available for image compression [2, 5]. A short review of these techniques is presented in section III. In this paper, we propose a novel saliency-based image compression technique to reduce the image file size without significantly reducing user satisfaction.

The images transmitted from the crowded environments under consideration in this paper will have some *salient objects*. For example, in an image of a soccer match, it is highly likely that the viewer will be more interested in the player and soccer ball movements, rather than other objects in the image. This implies that some objects in the image will be considered more important (salient) than others. This importance will be based on a number of visual, as well as, cognitive factors. The recipients of the images will be more interested in these objects than other parts of the image. Accordingly, as long as the quality of the salient objects in the image remains high, it's expected that the user satisfaction will also remain high, irrespective of the quality of the non-salient objects.

Our proposed scheme of user satisfaction driven bandwidth allocation for image transmission takes advantage of salient object detection effort in the image processing domain [7, 8, 5, 3, 6]. We recognize that at the present time, due to privacy issues, the NSPs are unable to see the image and as such cannot run any salient object detection algorithm on it. However, we envisage a scenario where the users may be willing to provide a waiver to the NSP to carry out *salient object detection algorithm* on the transmitted image, particularly if it contributes to enhanced user satisfaction. In the following section we explain our scheme in detail.

2. User Satisfaction Driven Bandwidth Allocation Scheme for Image Transmission

In our model, we assume that n customers, C_i, $1 \le i \le n$, are attempting to transmit one image each, I_i, $1 \le i \le n$, simultaneously. The size of image I_i, $1 \le i \le n$, ($x \times y$ inches), is denoted by S_i and the resolution of I_i (z dpi) is denoted by R_i. The size of the corresponding image file, denoted F_i is given as the product of S_i and R_i, i.e., $F_i = S_i \times R_i$. The NSP controls one or more *gateways* near the event venue, whose combined bandwidth is denoted by B. We assume that each customer C_i has a declared *Acceptable User Satisfaction Threshold* $AUST_i$ (τ_i). We also assume that the NSP has some customer profile information from which τ_i for customer C_i can be estimated. The NSP needs to adopt a policy to decide on the amount of bandwidth to allocate to customer C_i (denoted by A_i) so that satisfaction of customer C_i should have *minimal* deviation from the threshold τ_i. Suppose that the bandwidth required by the customer C_i to attain satisfaction threshold τ_i is SA_i. Due to fixed (and limited) bandwidth B that is available to the NSP, it is conceivable that at times $\sum_{i=1}^{n} SA_i$ will be greater than B. In such circumstances, the NSP has to allocate bandwidth A_i to customer C_i, where $A_i \le SA_i$. Clearly, such an allocation will cause *user dissatisfaction*. The goal of the bandwidth allocation policy of the NSP is to *minimize* user dissatisfaction.

In order to realize the NSP's objective of minimizing user dissatisfaction (or maximizing user satisfaction), one first needs a quantifiable way of measuring user satisfaction. In our model user satisfaction is a function of *quality* of the received image and the *delay* encountered while receiving the image. We denote the quality of image I_i as IQ_i and *delay* encountered by I_i as δ_i. The user satisfaction of customer C_i is denoted by US_i is taken to be a function of IQ_i and δ_i, i.e.,

$$US_i = f_1(IQ_i, \delta_i) \quad (1)$$

The quality of image IQ_i is a function of image size S_i, resolution R_i and a third parameter referred to as the *saliency concordance metric* (SCM_i) (see section IV).

$$IQ_i = f_2(S_i, R_i, SCM_i) \quad (2)$$

The delay encountered by customer C_i is a function of the image file size F_i and the bandwidth allocated to C_i by the NSP (A_i) and is obtained by dividing F_i by A_i:

$$\delta_i = f_3(F_i, A_i) = \frac{F_i}{A_i} \quad (3)$$

3. Review of Image Compression Techniques

In this section, we first review saliency-based and non-saliency-based standard image compression techniques. This is followed by our proposed saliency-based user satisfaction scheme.

3.1. Non-Saliency-Based Standard Image Compression

Usually image compression is generally guided by standard compression schemes like JPEG (Joint Photographic Experts Group) and JPEG2000 which are independent of image context information. The JPEG algorithm operates on the YCbCr color space, where Y channel contains luminance information and Cb and Cr channels carry color information. As our visual system is more sensitive to luminance than color, the color information from the two channels are down-sampled in both the horizontal and vertical directions. This is followed by partitioning of each image channel into blocks of 8×8 pixels. Compression is applied on each image block on all the three channels. The technique initiates by applying Discrete Cosine Transformation over a 8×8 block, yielding a 8×8 matrix of DCT coefficients as a replacement of the original 64 pixel values. Based on the image quality demanded, the compression algorithm selects an appropriate quantization table of size 8×8. This table is used to divide the DCT coefficient matrix values. In order to favor small gradual tonal changes over high-frequency transitions, the division operation rounds off to the nearest integer. A consequence of this quantization step is reduction of the variation in matrix values- the resulting matrix values will likely have same values or be zeros. Representation of such matrices having numbers that are either similar or zero is significantly effective for compression. The process terminates by compressing these coefficients by an arithmetic/Huffman encoding scheme, which leads to further reduction of file size.

The JPEG2000 standard [2] compresses images in a similar way as the JPEG format, with a major change in the transformation step- the usage of Discrete Wavelet Transform (DWT) in place of DCT yields better image quality at very high compression efficiency.

3.2. Saliency-Based Image Compression

Recognition of contextual cues aids in capturing underlying inter-relationships between objects of particular interest from a given image, and forms a task of paramount significance in the image processing and computer vision community. Consequently, automated identification and localization of these visually interesting regions, consistent with human perception, finds a wide range of applications. Along with extracting semantically meaningful descriptions of objects, exclusive processing of salient objects yields a compact region-based description of an image. Standard compression schemes like JPEG, JPEG2000 do not capture these semantic information, and severely degrade salient region data. This can be circumvented by utilizing image compression techniques that prevent the degradation of salient regions at low bit-rates [3, 4], and also reduce the cost of image storage and transmission. The filtered regions of an image can be explicitly handled, transmitted and re-constructed at the receiver end.

Being a classical problem of computer vision, salient object detection have been extensively studied in the last few years [7, 6, 5]. In [5], the authors proposed a new compression technique and used context-aware object detection framework proposed in [6, 7]. In our scheme, we use a novel salient object detection technique, which is distinctly different from the one proposed in [6, 7]. This scheme is discussed in detail in the next section. For the sake of completeness, we provide a short review of the saliency-guided compression scheme used in [5]. The technique progresses along two paths:

Generation of wavelet saliency map: The salient-object identification initiates with context-aware object detection [6, 7], which locates regions with different degrees of saliency. After object detection in a given image (through implementation of context-aware algorithm similar to Cadena et. al. [8]), we use a new technique to identify the salient regions with different levels of importance, which described in the next section. The magnitude of importance of a particular region is portrayed by its pixel values in the saliency map, with higher pixel values signifying higher saliency. In order to avoid the overhead of processing arbitrarily-shaped regions of interest in the saliency map, each region is approximated with a rectangular bounding box having a constant saliency value. In the subsequent stage, a transformation from the rectangular spatial saliency map to a wavelet domain saliency map is performed, so as to choose the coefficients that will be transmitted first.

For a wavelet coefficient, the wavelet saliency is defined as the summation of pixel values at all those points which have non-zero values of wavelet basis function. For a given image I and the corresponding spatial saliency map s_I, the original image dimensions is resized to *M* and *N*, where $M, N \equiv 0 (mod\ 2^K)$ and *K* being the number of levels in the desired wavelet decomposition. The following equation is used to recursively compute the wavelet saliency s_w^k for Low-Low (LL) bands using Haar wavelet transform, where k denotes the decomposition level $(k \in \{0,1,2,\ldots,K-1\})$:

$$s_w^{k+1}(i,j) = \sum_{i'=2i-1}^{2i} \sum_{j'=2j-1}^{2j} s_w^k(i',j') \tag{4}$$

Here $i = 1, 2, \ldots \frac{M}{2^k}$ and $j = 1, 2, \ldots \frac{N}{2^k}$. The basis of the recursion in equation (1) is $s_w^0(i,j) = s_I(i,j)$, where $s_I(i,j)$ is the spatial saliency at (i,j) . In order to expedite the wavelet transformation process, the wavelet saliency values of Low-Low (LL) band is copied to the corresponding locations of the Low-High (LH), High-Low (HL) and High-High (HH) bands. Now, with a spacial saliency value of 1 for the background, the wavelet saliency values will be in multiples of $4k$ for $k \in \{1,2,\ldots,K\}$ (since Haar wavelet's support is 4 pixels). Now, if a spatial saliency value of $4k'+1$ is used $(k' \in N)$ for salient regions, k' levels of salient region wavelet coefficients will be transmitted before the K^{th} level of background wavelet coefficients. In other words, the salient regions are k levels ahead from the background in terms of saliency.

Generation of quantized wavelet transform coefficients: This module initiates by performing Haar wavelet transform on the YCbCr image equivalent of the original RGB image. As the human visual system is more sensitive to luminance than chrominance, sub-sampling of both the Cb and Cr channels are performed, both horizontally and vertically, by assigning the LH, HL and HH wavelet coefficients to zero at the best scale.

Quantization of these wavelet transform coefficients are obtained on a sub-band basis. After being mean-subtracted, each sub-band is scaled to an 8-bit integer. A part of the coefficients is then chosen for transmission using the first step, as indicated by bitrate requirements. The selected coefficients, sequentially ordered by saliency, are written into a binary file. This file is then subjected to two-fold entropy coding- the first technique being LZ77 algorithm, followed by Markov chain based range coding [9]. The resulting file is transmitted as per the bit-rate constraints, along with the mean and scaling factors of the selected coefficients.

The received bounding box data is utilized to reproduce the original saliency map. An identical wavelet transform algorithm is deployed to compute the equivalent wavelet saliency map. Using these information, the decoder decodes the wavelet transform coefficients and assigns them in accurate locations in the wavelet decomposition structure. Re-scaling of each coefficient for every sub-band is performed, using corresponding scale coefficient and mean value, followed by an inverse wavelet transform. The resultant image will be in YCbCr color space, which is further subjected to transformation in the RGB color space to reconstruct the sent image. Figure 1 shows a reconstructed image for JPEG, JPEG-2000 and the saliency-based compression algorithm presented in [5] (image obtained from the UMD faces dataset).

Figure 1: (a) Original Image, (b) Reconstructed JPEG image, (c) Reconstructed JPEG-2000 image, (d) Reconstructed image using the compression algorithm in [5] (Picture courtesy [5]).

4. Saliency-Based User Satisfaction Scheme

As noted earlier, user satisfaction is a function of image quality and delay. Image quality in turn is a function of image size, image resolution and *saliency concordance metric*. High user satisfaction is ensured by high image quality and low delay. Both image quality and delay are dependent in image file size. In general, high quality image increases the image file size, which in turn increases transmission delay. Since user satisfaction depends on both image quality and delay, the NSP has to carefully balance conflicting requirements of image quality and delay to maximize user satisfaction. The underlying assumption of the saliency based user satisfaction scheme is that as long as the quality of the salient objects in the image is high, user satisfaction will also remain high, irrespective of the quality of the non-salient objects. Various techniques for extraction of *salient objects* from an image are known [5, 7, 6]. The image Ii may comprise of object set O_i and is given as $O_i=\{O_{i,1},O_{i,2},\ldots,O_{i,}p_i\}$. In order to reduce the file size, the NSP sends only q_i, $(q_i < p_i)$ *most salient objects* in Oi to the receiver and the receiver reconstructs the image with this set of objects. In order for the NSP to send the qi most salient objects, the NSP first has to *rank* the objects in the set Oi in order of their *saliency* from the perspective of the customer. The NSP most likely will not accurately know the customer perspective of the objects from the saliency standpoint. However, the NSP can *estimate* the customer perspective with a certain degree of confidence if the NSP has some knowledge of customer preference. We assume the NSP maintains a repository of images transmitted by the user over a period of time to understand that user's preference and perspective. The image repository of customer Ci is denoted by IR_i and comprises of images $IR_{i,1}$, $1\le i \le r_i$, i.e., $IR_i = \{IRi_{,1}, IRi_{,2},\ldots, IR_{i,}r_i\}$. Let $IR_i^k \subseteq \mathrm{IR_i}$ denote the subset of images in the image repository IR_i that contains the object $O_{i,k}$, $1 \le k \le p_i$, an object in the set Oi. Let $C(I_i, IR_i^k)$ be the image in the set IR_i^k that is *closest* to the image I_i according to some *proximity/similarity* measure, such as Spatial Pyramid Matching [13]. Let $CIS(I_i) = \cup_{\mathrm{k}=1}^{p_i} C(I_i, IR_i^k)$ denote the set of images closest to I_i that contains the object $O_{i,k}$, $1\le k\le p_i$. The NSP's estimated *rank* of the object $O_{i,k}$ from the user perspective will be equal to the rank of the image $C(I_i, IR_i^k)$ in the set $CIS(I_i)$ in terms it's proximity to the image Ii according to some proximity measure [13].

Using the ranking function defined above, the salient objects in the set $O_i=\{Oi_{,1},Oi_{,2},\ldots,O_{i,}p_i\}$ are ranked from the *highest* to the *lowest*. After this ranking, q_i highest ranked objects are selected for transmission to the sender. The *Saliency Concordance Metric* of image I_i is given as the ratio of q_i to p_i , i.e., $SCM_i = \frac{q_i}{p_i}$.

Earlier we stated that the quality of image I_i (IQ_i) is given as function of image size, resolution and *Saliency-Concordance Metric*. Now, we define the function $f_2(*, *, *)$ as :

$$f_2(S_i, R_i, SCM_i) = \omega_1 \frac{S_i'}{S_i} + \omega_2 \frac{R_i'}{R_i} + \omega_3 SCM_i \quad (5)$$

where ω_1, ω_2 and ω_3 represents *weights* associated with *normalized* size and *normalized* resolution and saliency concordance metric SCM_i , with ω_1+ω_2+ω_3=1. S_i' and R_i' represent the size and the resolution of the original image supplied by the sender and S_i' and S_i' represent the size and the resolution of the image actually transmitted by the NSP, after transforming the image through the salient object detection and modification algorithm.

Once the size S_i' and resolution S_i'R'i of the image I_i is determined, it's file size FS_i' is also determined. The delay δ_i encountered for transmission of this file depends on the bandwidth A_i allocated by the NSP for transmission of this file. As user satisfaction is given by the first equation, we need to identify the function $f_1(*, *)$ that maps a combination of IQ_i and δ_i to US_i. We propose a machine learning based technique to determine the function $f_1(*, *)$. As indicated earlier, in our model the NSP maintains a repository of images that were sent by the user. This repository, in addition to the images, also stores the image quality IQ_i and delay δ_i for each of the images. Moreover, in our model we assume that the NSP through questionnaire survey of the customer acquires the information regarding user satisfaction US_i for each of the images transmitted. The information regarding IQ_i, δ_i and the corresponding US_i can be maintained in a survey table. By applying appropriate machine learning algorithm, the function $f_1(*, *)$ can be computed with a high degree of accuracy.

We assume that each customer Ci has a declared *Acceptable User Satisfaction Threshold* $AUST_i$ (τ_i). When an image I_i is transmitted by the NSP, the actual value user satisfaction US_i corresponding to this image, may or may not exceed the $AUST_i$. If US_i is smaller than $AUST_i$, the customer will be dissatisfied. In our model instead of treating user satisfaction as binary valued (satisfied or dissatisfied), we measure the *degree of user dissatisfaction* as the *difference* between US_i and $AUST_i$. We conceive of two different objectives for the NSP. One objective may be to *minimize total dissatisfaction*, i.e.,

$$minimize \sum_{i=1}^{n} |\, US_i - \tau_i| \quad (5)$$

The second objective may be to *minimize the maximum dissatisfaction*, i.e.,

$$minimize \max_{i=1}^{n} \,|\, US_i - \tau_i| \quad (5)$$

The NSP has to minimize either one of the above two objectives, subject to the constraint that total allocated bandwidth to n customers cannot exceed the available bandwidth B , ie.,

$$\sum_{i=1}^{n} A_i \leq B \quad (5)$$

We propose the use of techniques such as Genetic Algorithms, Simulated Annealing or Tabu Search for finding the optimal bandwidth allocation that realizes the objectives, subject to available bandwidth constraint.

5. Conclusion

In this paper, we have presented a framework for saliency-based user satisfaction scheme. Our scheme relies on two key-features. First, to circumvent the biased realization of user-satisfiability with a generalized non-linear function, we propose a framework for quantifying user-satisfiability, based on customer profile. Second, in contrast to classical image compression technique, we propose a novel context-aware image compression scheme to reduce image file size. We are currently in the process of incorporating the ideas proposed in this paper in an experimental setup and evaluate the efficacy of our approach.

References

[1] F. R. M. Lima, E. B. Rodrigues, T. F. Maciel, m. Nordberg, "Resource Allocation fo Imoproved User Satisfaction with Applications to LTE" In Resource Allocation and MIMO for 4G and Beyond, Edited by F. R. P. Cavalcanti, Springer Scince + Business Media, New York 2014.

[2] Skodras, Athanassios, Charilaos Christopoulos, and Touradj Ebrahimi. "The JPEG 2000 still image compression standard." IEEE Signal processing magazine 18, no. 5 (2001): 36-58.

[3] Sanchez, Victor, Anup Basu, and Mrinal K. Mandal. "Prioritized region of interest coding in JPEG2000." IEEE Transactions on Circuits and Systems for Video Technology 14, no. 9 (2004): 1149-1155.

[4] Sanchez, Victor, Mrinal Mandal, and Anup Basu. "Robust Wireless transmission of regions of interest in JPEG2000." In Image Processing, 2004. ICIP'04. 2004 International Conference on, vol. 4, pp. 2491-2494. IEEE, 2004.
[5] Barua, Souptik, Kaushik Mitra, and Ashok Veeraraghavan. "Saliency guided Wavelet compression for low-bitrate Image and Video coding." In Signal and Information Processing (GlobalSIP), 2015 IEEE Global Conference on, pp. 1185-1189. IEEE, 2015.
[6] Stauffer, Chris, and W. Eric L. Grimson. "Adaptive background mixture models for real-time tracking." In Computer Vision and Pattern Recognition, 1999. IEEE Computer Society Conference on., vol. 2, pp. 246-252. IEEE, 1999.
[7] Viola, P., and M. J. Jones. "Robust real-time face detection, International Journal of Computer Vision, vol. 57, no. 2." (2004).
[8] Cadena, Cesar, Anthony Dick, and Ian D. Reid. "A fast, modular scene understanding system using context-aware object detection." In Robotics and Automation (ICRA), 2015 IEEE International Conference on, pp. 4859-4866. IEEE, 2015.
[9] Ziv, Jacob, and Abraham Lempel. "A universal algorithm for sequential data compression." IEEE Transactions on information theory 23, no. 3 (1977): 337-343.
[10] Chang, Cheng-Chun, Tien-Ying Kuo, Yi-Chung Lo, Heung-No Lee, David Askey, and Zhi-Hong Mao. "User-satisfaction based bandwidth allocation for transmission of multiple sources of human perceptual data." Journal of the Franklin Institute 349, no. 3 (2012): 879-890.
[11] Pal, Sourav, Sajal K. Das, and Mainak Chatterjee. "User-satisfaction based differentiated services for wireless data networks." In Communications, 2005. ICC 2005. 2005 IEEE International Conference on, vol. 2, pp. 1174-1178. IEEE, 2005.
[12] Suzuki, Kenta, Hiroki Nishiyama, Nei Kato, Hirotaka Ujikawa, Ken-Ichi Suzuki, and Naoto Yoshimoto. "A bandwidth allocation method to improve user QoS satisfaction without decreasing system throughput in wireless access networks." In Personal Indoor and Mobile Radio Communications (PIMRC), 2012 IEEE 23rd International Symposium on, pp. 1430-1435. IEEE, 2012.
[13] Lazebnik, Svetlana, Cordelia Schmid, and Jean Ponce. "Beyond bags of features: Spatial pyramid matching for recognizing natural scene categories." In Computer vision and pattern recognition, 2006 IEEE computer society conference on, vol. 2, pp. 2169-2178. IEEE, 2006.
[14] Song, Qing Yang, Ming Hong Yue, and Zhao Long Ning. "A Satisfaction-Based Dynamic Bandwidth Allocation Algorithm for Heterogeneous Wireless Network." In Applied Mechanics and Materials, vol. 220, pp. 2004-2007. Trans Tech Publications, 2012.

Sandipan Choudhuri received his Bachelor's and Master's degree in Computer Science and Engineering from West Bengal University of Technology and Jadavpur University, India, in the year 2013 and 2015 respectively. He worked as a Junior Research Fellow in the Computer Science and Engineering department of Jadavpur University from 2015 to 2017. He is currently a PhD student in Computer Science at Arizona State University. His current research interests include image processing and computer vision.

Kaustav Basu completed his Bachelor's and Master's degrees in Computer Science in 2014 and 2016 respectively. He is currently a PhD student in Computer Science at Arizona State University. His interests are the application of graph theory and machine learning, in the field of sports.

Dr. Arun Sen is a Professor of Computer Science and Engineering at Arizona State University. His expertise is in network modeling and optimization. He has over a hundred research publications in peer reviewed journals and conferences on various aspects of networks. In recent times his research is supported by the AFOSR, DTRA, ONR, ARO and the NSF. He served as an Associate Editor of the IEEE Transactions on Mobile Computing. He was a Visiting Scholar at University of California, Berkeley, University of California at San Diego, University of Passau in Germany and Wroclaw University of Science and Technology in Poland. In 2015, he was a Fulbright Fellow at INRIA at their North European Research Center in Lille, France. He started the International Workshop on Network Science for Communication Networks (NetSciCom) in 2009. The ninth edition of the workshop took place in conjunction with IEEE Infocom in 2017 in Atlanta