(JESC) The Journal of Engineering Science and Computing, Issue I, Volume I, April, 2019

Charging Connected and Autonomous Electric Vehicles in Smart Cities

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Abstract

In coming years, attraction to alternative urban mobility paradigms such as Connected and Autonomous Electric Vehicles (CAEVs) will increase as CAEVs can significantly contribute to not only optimize traffic flow and improve road safety but also minimize dependence on fossil fuel and reduce carbon emission in urban areas. Nonetheless, there are several barriers towards widespread adoption of CAEVs. In order to have significant growth of CAEVs in urban areas, adequate number of charging facilities in urban areas is needed. However, getting information of the available charging stations is still challenging. Furthermore, the waiting time at the charging stations may be unpredictable. Thus an efficient smart CAEV charging management is required for managing and allocating charging station resources from different charging operators. In this paper, we have designed and implemented a CAEV charging management system that utilizes automated reservation based charging strategies which include effective reservation management and efficient allocation of time slots of wireless charging stations. And we have conducted preliminary evaluations on various charging parameters.

Keywords

Connected and Autonomous Electric Vehicles (CAEVs); Smart city; Smart CAEV charging; Automated reservation.

شحن السيارات الكهربائية المتصلة والمستقلة في المدن الذكية

الملخص: في السنوات القادمة، سيزداد الجذب على نماذج التنقل الحضرية البديلة مثل السيارات الكهربائية المتصلة والحركية (ج ا إ ف) حيث يمكن أن تساهم بشكل كبير في تحسين تدفق حركة المرور وتحسين السلامة على الطرق ولكن أيضًا تقليل الاعتماد على الوقود الأحفوري وتقليل انبعاثات الكربون في المناطق الحضرية. ومع ذلك، هناك العديد من الحواجز التي تحول دون اعتمادها على نطاق واسع. من أجل تحقيق نمو كبير في المناطق الحضرية، هناك حاجة إلى عدد كاف من مرافق الشحن في المناطق الحضرية. ومع ذلك، فإن الحصول على معلومات حول محطات الشحن المتاحة لا يزال يمثل تحديًا. علاوة على ذلك، وقت الانتظار في محطات الشحن قد لا يمكن التنبؤ بها. وبالتالي، فإن إدارة الشحن الذكية تتسم بالكفاءة لإدارة وتخصيص موارد محطة الشحن من مشغلي الشحن المختلفين. في هذه الورقة، قمنا بتصميم وتنفيذ إدارة شحن (ج ا إ ف) النظام الذي يستخدم استراتيجيات الشحن الآلي القائمة على الحجز والتي تشمل الإدارة الفعالة للحجز والتخصيص الفعال للفواصل الزمنية لمحطات الشحن اللاسلكي. وقمنا بإجراء تقييمات أولية على معايير الشحن المختلفة.

1 Introduction

More than half of the world's population live in urban areas now, and it is anticipated to reach 80% by 2050 [1].

With rapid urbanization, transportation related issues have posed a major impediment to sustainable development for many cities. For instance, the increasing demand for mobility yields significant greenhouse gas (GHG) emissions and thus causes environmental problems (i.e. air pollution, climate change) due to the transportation using internal combustion engines (ICEs) [2].

Futhermore, urban transportation systems are confronting significant challenges owing to the drastic increase in vehicle ownership that yields increased road congestion, longer travel times, growing parking demand as well as larger carbon footprint.

Smart cities, from a transport perspective, should effectively tackle the mobility challenge of rapid urbanization and growing traffic congestion [1, 3].

Connected and Autonomous Electric Vehicles (CAEVs) [4] could be a potential solution to urban transportation problems and thus for mitigating the impact of carbon emissions and climate change.

CAEVs that use emerging communication technologies, deep learning techniques, and highly efficient batteries could transport people more efficiently, without the need for drivers or fossil-fuel based ICEs [5].

Wide adopation of CAEVs could reduce environmental degradation through reduced CO_2 emissions while furnishing beneficial economic and social outcomes through improved efficiency, traffic flow, road safety, and greater access [6].

Given the advantages of cleaner and reliable transport, CAEVs could potentially accelerate significantly greenhouse gas emissions reductions in the transport sector and would be beneficial for urban environments such that to improve quality of life in urban area.

Though CAEVs may have the capacity to change the landscape of transportation, recharging CAEVs in the urban area might be challenging.

For the wide-scale deployment of CAEVs in urban areas, significant number of charging facilities should be deployed in urban areas such that CAEVs can recharge whenever they desire.

Although fast charging facilities are emerging, still charging is almost limited to chargers at homes, businesses and public places where recharging takes hours compared to refuelling the ICE-enabled vehicle which takes just a couple of minutes. So CAEVs may have to face longer waiting time at the charging stations. Thus, an efficient smart CAEV charging management is required for managing and allocating charging station resources.

This paper presents automated reservation based charging strategies and depicts implementation of a system that can provide effective automated reservation for CAEVs. One of the objectives is to minimize waiting time at the charging stations.

Other significances of this system are to alleviate the challenges related to allocation of charging station resources in dense urban area, especially during peak (rush) hour and to assure convenience of automated and coordinated charging strategies.

The remainder of this paper is organized as follows. Section II highlights Related works while Section III describes Connected and Autonomous Electric Vehicles. Similarly, Section IV introduces CAEV Charging Management System. Automated Reservation Mechanism is described in Section V, while deployment of SecCharge CAEV system is depicted in Section VI. Finally, Section VII provides conclusions.

2 Related Works

Autonomous vehicle (AV) technologies have been progressing at a very rapid pace over the past decade. Typically, the technological advancement for AV accelerated in 2015. And in recent years, Connected and Autonomous Vehicle (CAV) as well as Connected and Autonomous Electric Vehicle (CAEV) technologies are considered as highly appealing automotive technologies.

Many companies are heavily investing in CAVs and adopting different approaches to bring the change in automotive industry. Typically, the companies working on CAVs can be categorized into Traditional Original Equipment Manufacturer (OEM) players and disruptive players. Traditional OEM players are companies that are already in the automotive business and disruptive players are those that have no significant background in automotive industry such as Waymo, Uber.

In recent years, there have been many researches and studies undertaken in the transportation domain related to CAVs and CAEVs [6, 7, 8]. Some of them focus on CAEV applications, for instance, the paper [9] proposes a secure automated valet parking using privacy-preserving reservation scheme for AVs.

It can be observed that the charging management of Battery Electric Vehicles (BEVs) [10, 11, 12] are well studied. For instance, in the paper [13], the authors have proposed smart charging strategies that incorporate unified Grid-to-Vehicle and Vehicle-to-Grid charging framework in order to provide optimal integration of plug-in electric vehicles (PEVs) within the existing distribution system infrastructure. Similarly, in [14, 15, 16], optimal scheduling mechanisms for charging electric vehicles (EVs) are depicted. However, these techniques may not suitable for CAEVs since CAEVs have unique characteristics such as vehicle autonomy.

Studies in charging management of CAEVs [17, 18, 19] are still in early stage. Major challenge in the charging management of CAEVs is due to the fact that there is less or no human intervention.

The paper [20] proposes an effective, autonomous proportional control scheme for charging EVs, which does not require any real-time communication between the EV and the utility. Whereas in the paper [21], the authors have proposed a multi-class dispatching and charging scheme which can be used for autonomous electric mobility on-demand (AEMoD) services. And the paper [22] investigates electricity use of fully autonomous electric vehicle (AEV) fleets in cities, which is based on a dial-a-ride system. Similarly, the paper [23] presents an AV public transportation system that supports point-to-point services with ride sharing capability as well as manages a fleet of AVs and accommodates a number of transportation requests. The authors focus on two major problems in the system: scheduling and admission control. However, these papers neither deal with reservation of the charging stations nor address issues of waiting time at the charging stations.

3 Connected and Autonomous Electric Vehicles

3.1 Overviews

Connected and Autonomous Electric Vehicles (CAEVs) are complex automotive systems, combining basically connected vehicles (CV), autonomous vehicle (AV) and electric vehicle (EV).

A connected vehicle (CV) is a vehicle with technology that enables it to communicate with nearby vehicles, infrastructure, as well as objects; but may not be automated nor electrically operated. While, an autonomous vehicle (AV) is a vehicle that is, in the broadest sense, capable of driving itself without human intervention. And electric vehicle (EV) is a vehicle that powers up and operates with energy stored in the battery.

Typically, CAEV is an electric vehicle that is capable of sensing its environment and navigating with little or no human input. CAEV senses its environment using various sensing devices including Radar, LiDAR (Light Detection and Ranging), image sensors, and 3D camera etc. Basically, CAEV is composed of five major components [5].

- Perception system which is responsible for sensing the environment to understand its surroundings.
- Localization and mapping system that enables the vehicle to know its current location.
- Driving policy refers to the decision making capability of a CAEV under various situations, such as negotiating at roundabouts, giving way to vehicles and pedestrians, and overtaking vehicles.
- Communication system: As CAVs will be connected to the surrounding environment such as vehicles with Vehicle to Vehicle connectivity (V2V), to the infrastructure with

Vehicle to Infrastructure (V2I) and to anything else such as the internet: Vehicle to Anything (V2X), through wireless communications links

- Storage Battery System: This system includes charger and battery packs in the vehicle. Basically State of Charge (SoC) level determines the amount of charge stored in the battery.

3.2 Need of CAEVs

CAEVs definitely transform existing mobility paradigm. It can be observed that technological advancements in driving assistants and network connectivity yield further opportunities and services and meet the sustainable development for cleaner, safer, and smarter mobility.

CAEVs offer many potential advantages in terms of sustainable development for environment friendly urban mobility, which are as follows.

- Improved safety: may eliminate many of the accidents caused by human error, estimated at about 90% of all accidents.
- Greater mobility: for those who cannot drive, including elderly, disabled, and youth.
- Reduced parking needs: passengers can be dropped off at their destinations without needing a nearby parking space.
- Relaxed drivers: drivers can rest, work, or entertain themselves during a trip.
- Increased car-sharing: reduced need for individually-owned cars.
- Increased road capacity: through fleet platooning, more predictable traffic flow, and reduced congestion
- Fewer CO_2 emissions and pollutants: using electric power to operate, can reduce GHG emissions as well as air pollution; minimized environmental impact; improve quality of life in urban area.
- Less fuel costs: Fossil fuel will not be consumed to run CAEV, so fuel consumption is significant reduced.

With wide adoptation of the CAEVs, it is expected to improve road safety, optimize traffic flow, help reduce fuel consumption, and minimize CO_2 emissions in the urban environments.

3.3 Vehicle Automation

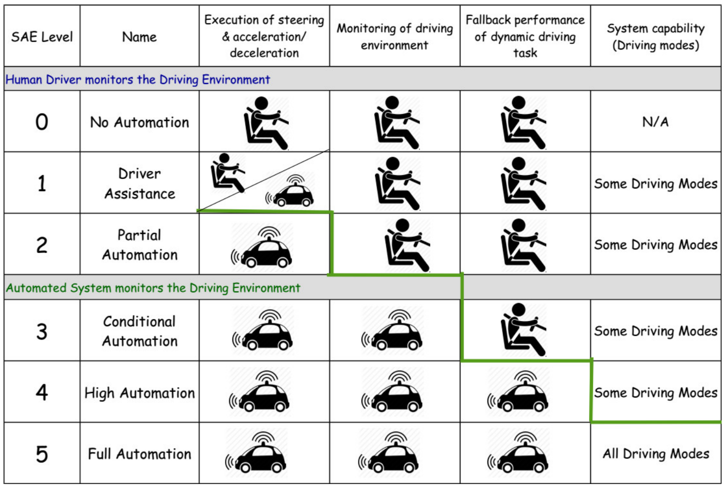
Society of Automotive Engineers (SAE) released SAE International Standard J3016 that sets out taxonomy and standard to define different levels of autonomy [24]. SAE updated its classification in 2016 as SAE J3016_201609.

Basically, vehicle automation has been categorized into various levels of autonomous vehicle technology ranging from Level 0, corresponding to no automation, to Level 5, corresponding to full automation. For instance, automated driver-assistance systems such as adaptive cruise control correspond to lower automation levels, while fully automated driverless vehicles correspond to higher automation levels.

The SAE defined levels of vehicle automation is depicted as follows.

> Level 0 – No Automation: In this level, the human driver is responsible for all the driving tasks including control of the car as well as monitoring the road and environment around the car. Level 1 – Driver Assistance: In this level, the human driver is assisted with either steering or acceleration/ deceleration by the driver assistance system but not both. For instance, adaptive cruise control. Level 2 – Partial Automation: In this level, the driver assistance system take care of both acceleration/ deceleration and steering control of the car, while the human driver monitors the road and environment around the car. It includes more advanced levels of driver assistance and requires continuous supervision of the driver. Level 3 – Conditional Automation: In this level, the automated driving system undertakes all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene. Thus it requires partial supervision of the driver. Level 4 – High Automation: In this level, the automated driving system undertakes all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene. This level is basically unsupervised. Level 5 – Full Automation: In this level, the automated driving system undertakes all aspects of the dynamic driving tasks in all roadway and environmental conditions. This level does not require driver at all.

Figure 1 shows SAE defined level of vehicle automation.



SAE Level	Name	Execution of steering & acceleration/ deceleration	Monitoring of driving environment	Fallback performance of dynamic driving task	System capability (Driving modes)
Human Driver monitors the Driving Environment					
0	No Automation	👤	👤	👤	N/A
1	Driver Assistance	👤 / 🚗	👤	👤	Some Driving Modes
2	Partial Automation	🚗	👤	👤	Some Driving Modes
Automated System monitors the Driving Environment					
3	Conditional Automation	🚗	🚗	👤	Some Driving Modes
4	High Automation	🚗	🚗	🚗	Some Driving Modes
5	Full Automation	🚗	🚗	🚗	All Driving Modes

Figure 1: SAE defined Level of Vehicle Automation

3.4 CAEVs in Smart Cities

Smart cities will contain fully-integrated infrastructure, including smart transport services, smart water/ electric grid systems, smart environment monitoring services and others. In turn, these smart systems shall accelerate efficiency and productivity, while improving quality of life.

One of the key components of smart cities are intelligent transportation solutions including CAEVs. For these vehicles to effectively and efficiently travel in the city, several infrastructure changes are required in order to accommodate them. One major change will be the implementation of Road Side Units (RSUs) along streets and highways. The RSUs, which are vital components of Intelligent Transportation Systems (ITSs), use public or private networks to send vital information to the CAEVs. With the help of these RSUs, CAEVs will be able to visualize activities far ahead on their routes.

Smart cities, able to integrate living space with efficient mobility solutions like CAEVs, will necessitate faster and better connectivity, as well as improved data storage. Through the use of emerging communication such as 5G, infrastucture that is complete with sensors will be able to capture surrounding information (such as traffic information) and transmit this data to CAEVs on the road. For instance, a sensor-equipped traffic light would be able to send information about light changes to CAEVs, allowing the latter to act properly.

Other major changes of smart cities will be alterations to the use of parking spaces and traffic flows. The smart cities will most likely see the benefits of intelligent transport if CAEVs are used shared services. With deployment of shared CAEVs, not only the demand for parking or garages will drastically decrease but also the traffic flows in the smart cities will be reduced, in turn, reducing traffic congestions.

4 CAEV Charging Management System

In this section, CAEV charging management system based on the SecCharge platform is presented. It consists of following key components: SecCharge CAEV server, Wireless charging station operators (WCSOs), and Energy service providers (ESPs). Figure 2 depicts a high level diagram for CAEV charging management system.

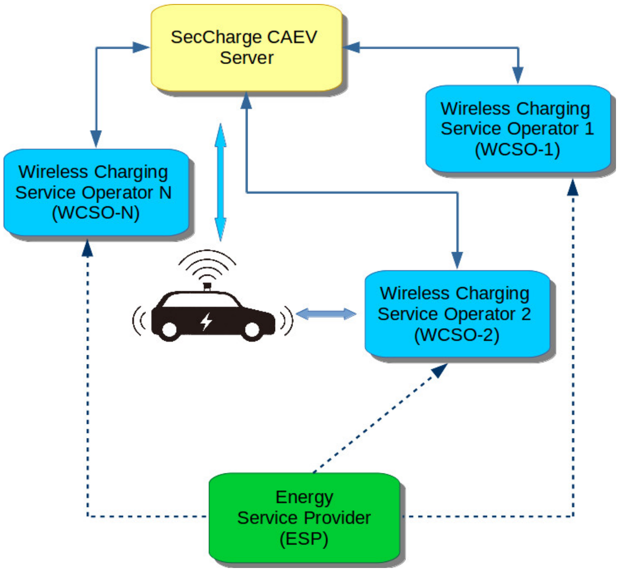


Figure 2: High level diagram for CAEV charging management system

ESPs are autonomous entities producing and distributing energy to the consumers. These consumers may be private (i.e. homeowners) or public (i.e. charging stations operators). Whereas, WCSOs are fundamentally accountable for operation and maintenance of wireless charging stations (WCSs). Typically, WCSOs may manage multiple WCSs at various charging sites/locations. As shown in Figure 2, a particular electric vehicle (EV) charging network may have several WCSOs such as WCSO-1, WCSO-2..,WCSO-N.

A SecCharge CAEV system, which is a central component of the system architecture, acts as a Smart Management Center (SMC) for EV charging. It is designed for facilitating charging services to the CAEVs by providing effectual coordination with various WCSOs in EV charging networks.

On one hand, SecCharge server may provide charging related services to CAEVs including finding WCS location, assigning reservation and managing CAEV information and financial transactions. On another hand, SecCharge server is responsible for interacting with WCSOs for efficient smart charging. The SecCharge CAEV system may establish agreements with different WCSOs in the EV network such that CAEVs can charge in the entire EV charging infrastructure.

Consequently, the SecCharge CAEV system is based on a centralized server that smartly manages charging related activities. In case of scheduling and reservation services, the system maintains reservation allocation information including occupied and available time slots, so that CAEVs may reserve the WCSs operated by different WCSOs. In the SecCharge CAEV charging management system, automated reservation mechanism is one of the main components.

4.1 System Functionality

Main functionality of the SecCharge CAEV Charging management system includes Data collection, Route/Trip planning, and Scheduling and Reservation services.

- Data collection service: CAEVs can obtain information on wireless charging stations (location, technical characteristics, current status). The system also obtains information (i.e. current State-of-charge, current location) from the CAEV and CAEV owner.
- Scheduling and reservation services: CAEVs can reserve the wireless charging stations operated by various WCSOs. The system collects all the information about the reservation. Reservation allocation information including occupied time slot and available time slots can be retrieved. Reservation can be modified, or deleted by the CAEV owner. CAEV owner can also view the historical data of his previous reservations. Detail explanation of automated reservation mechanism is provided in Section 5.

5 Automated Reservation Mechanism

In this section, automated reservation mechanism is proposed for SecCharge CAEV Charging Management System [25].

For the wide deployment of the battery electric vehicles (BEVs) as well as CAEVs, a range anxiety is one of the major issues. In order to minimize such an anxiety, charging CAEV in a timely fashion is imperative to guarantee a certain degree of its mobility. However, for EV/CAEV charging, the waiting time at the charging stations is still challenging issue.

Similar to EVs, CAEVs are concerned with charging process as the charging time is still significantly long especially with Level 2 charger. As wireless charging being in very early stage, the charging time is same as with Level 2 charger. Possibly, long charging times may cause considerable delays, owing to not only the CAEV charging process, but also the waiting times due to busy charging stations.

Furthermore, unlike EVs, CAEVs especially level 4 and 5 would driver assistance system shall take most of the tasks, so CAEVs would be responsible for timely charging as well.

In the future, number of CAEVs will increase significantly in the urban areas, then they may experience congestion at several WCSs. Since waiting in queue at the charging stations may not be convenient for CAEVs, the system should be able to provide current waiting time for the WCSs such that the CAEVs would recharge accordingly. This would help to curtail queuing time at the WCSs.

In this paper, we have proposed a novel automated reservation mechanism for charging CAEVs. By deploying an automated reservation mechanism, the CAEVs can reserve recharging schedule ahead of time, so such a strategy can not only minimize waiting time but also alleviate congestion at the charging stations (i.e. recharging congestion).

Primarily, SecCharge CAEV system embraces charging strategies based on slotted reservation where, a 24-hour period is divided into time slot intervals, for instance, δ is set at 15 min in our case. Table 1 shows the notations used in the scheme.

Table 1: Notations used in the scheme

Symbol	**Description**
SoC_{max}	Upper limit of SoC level
SoC_{cr}	Critical SoC level
SoC_{th}	Threshold SoC level for a given CAEV
SoC_{tar}	Targeted SoC level for a given CAEV
ϵ	Total energy gained from SoC_{th} to SoC_{tar}, kWh
$t_{\text{tar}}^{\text{th}}$	Charging time required from SoC_{th} to SoC_{tar}
t_{tra}	Travel time to the WCS
t_{arr}	Arrival time at the WCS
t_{wa}	Waiting time at the WCS
t_{s}^{r}	Reservation start time
t_{f}^{r}	Reservation finish time
τ^{r}	Reservation duration
η	Number of time slots
δ	Time slot interval
Loc_{cur}	Current location of a given CAEV
$Dest$	Destination to be reached by a given CAEV

Automated reservation allocation scheme is a strategic constituent of the charging strategies. The automated charging module gets information from the sensing unit to determine the state of charge (SoC) of the CAEV. A threshold SoC for a CAEV SoC_{th}, say 25%, is an initial desired SoC level for recharging a particular CAEV. A critical SoC SoC_{cr} is bare minimum SoC level in the CAEV. It should be noted that SoC_{th} must be greater than SoC_{cr}.

Thus as soon as current SoC reaches SoC_{th}, it will send an alert and triggers Reservation Request (Reserve_Req).

In automated reservation allocation scheme, the CAEV sends Reserve_Req, which has 3-tuple $\{SoC_{\text{th}}, Loc_{\text{cur}}, Dest\}$, to the SecCharge CAEV system indicating that the CAEV needs recharging. Figure 3 depicts message flows for CAEV Charging.

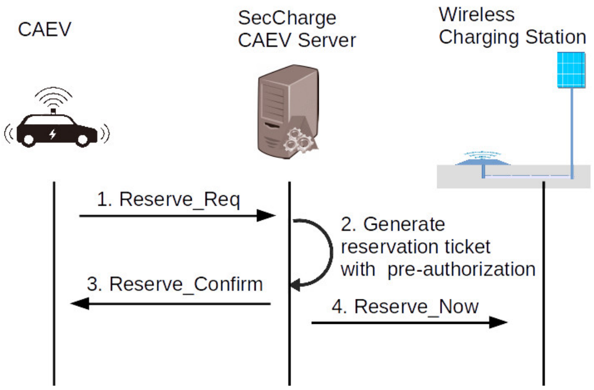


Figure 3: Message Flows for CAEV Charging

Upon receiving Reserve_Req, the SecCharge CAEV Server shall deploy an algorithm for determining appropriate SoC level and reserving time slots with an appropriate charging station. Figure 4 depicts an algorithm flow for the automated reservation.

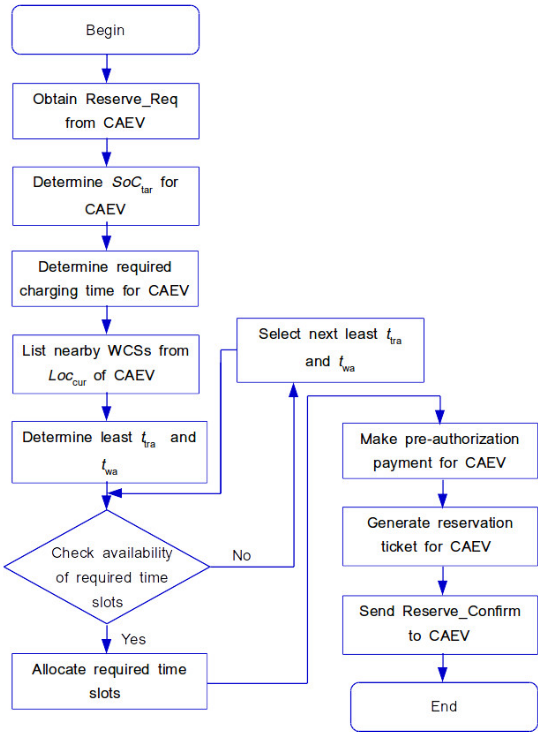


Figure 4: Flow for Automated Reservation Algorithm

Target SoC level for recharging is given by:

$$SoC_{\text{tar}} = \alpha\left(SoC_{\max} - SoC_{\text{cur}}\right)$$

where α is a coefficient for recharging, such that $\alpha \in \{0, 1\}$.

Determination of α depends on various factors such as distance to be travelled, a location of a WSC (i.e. downtown or suburb) and time of day (peak hour or wee hour). As SecCharge CAEV server is responsible for determining α, in turn, SoC_{tar} for each CAEV, a slot allocation in WSC will be optimal.

Required charging time t_{char} is computed as:

$$t_{\mathrm{char}} = SoC_{\mathrm{tar}} \times \frac{Q}{CR_x \times \mu}$$

where Q is CAEV's battery capacity (kWh); CR_x is charge rate; μ is CAEV charging efficiency, typically, $\mu = 0.9$.

While computing t_{char}, CR_x should be considered with lower value of either the vehicle's acceptance rate or the WSC power output rate.

With the list of nearby WSCs, the SecCharge CAEV Server shall compute travel time (t_{tra}) to each WCS as well as waiting time (t_{wa}). The waiting time (t_{wa}) is the time between the arrival time (t_{arr}) of the CAEV to the WSC and the time that the CAEV starts to receive charging service.

Then the SecCharge CAEV Server shall determine the WSC with the least t_{tra} and t_{wa} and check if the required time slots are available in the given WSC.

If the required time slots are not available, then the SecCharge CAEV Server shall choose the next WSC with lower t_{tra} and t_{wa}.

After allocating the time slots in the given WSC, the SecCharge CAEV Server shall generate Reservation ticket, which has reservation information. At least, the reservation information for the CAEV shall have Reservation start time($t_{\mathrm{s}}^{\mathrm{r}}$), Reservation finish time ($t_{\mathrm{f}}^{\mathrm{r}}$) and information on WSC location.

Reservation finish time and reservation duration can be computed as follows.

$$\begin{aligned} t_{\mathrm{f}}^{\mathrm{r}} &= t_{\mathrm{s}}^{\mathrm{r}} + \eta \times \delta \\ \tau^{\mathrm{r}} &= t_{\mathrm{f}}^{\mathrm{r}} - t_{\mathrm{s}}^{\mathrm{r}} \end{aligned}$$

After successful pre-authorization payment with help of the Payment gateway, the status changes to 'payment pre-authorized'. Upon successful generation of the reservation ticket, the SecCharge CAEV server shall send a confirmation for automated reservation (Reserve_Confirm) to the CAEV. In the meantime, the SecCharge CAEV server shall also send the automated reservation details (Reserve_Now) with τ^{r} in order to reserve time slot(s) at the given WCS.

Upon receiving Reserve_Confirm, the CAEV can obtain a desired route to re-route via the given WCS.

6 Deployment of SecCharge CAEV System

This section describes the deployment of SecCharge CAEV Charging Management system. It includes real-world implementation in a testbed as well as case studies and analysis.

6.1 Implementation in Testbed

SecCharge CAEV system utilizes combination of client-server, web-based and mobile architecture. It has several key components such as back-end servers, Control center server, and payment gateway modules.

At the back-end, it consists of Application server, Database server and Authentication server. The back-end system is connected to the payment gateway for financial transaction. The client can access to the back end system through mobile or web applications.

The back-end server has connection to the Control center server for accessing wireless charging stations. Figure 5 depicts system architecture for SecCharge CAEV Charging Management System.

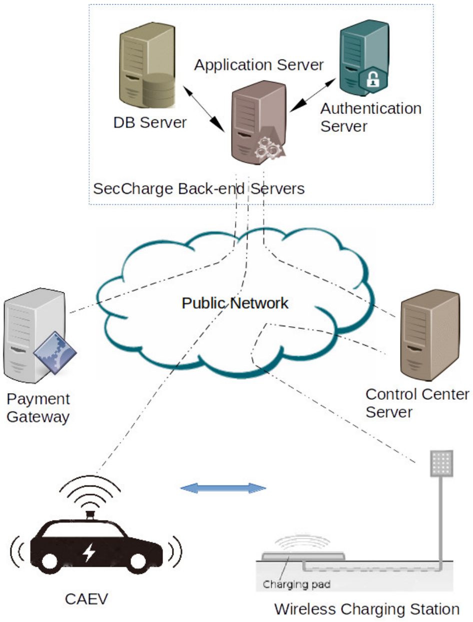


Figure 5: Testbed for SecCharge CAEV Charging Management System

The technical specifications of the SecCharge CAEV system are discussed as follows.

The SecCharge application is built on Model View Controller (MVC) architecture. MVC architecture divides application into three parts which are interconnected and have loose coupling. Loose coupling among these three components allows code reuse and easy code modification.

- Model: A model stores information that is recovered from the controller and showed in the perspective user interface view.
- View: A view is graphical user interface that creates a yield presentation to the client in light of changes in the model.
- Controller: A view controller creates a yield perspective and an inserted controller. It manages the interaction between the view and model.

The MVC architecture is implemented using the Spring framework which is generally referred as Spring MVC.

Oracle Express edition has been used as the database for application due to its highperformance speed and multiple databases support. Hibernate is an ORM (Object Relational Mapping) API which abstracts the SQL from developers. This allows developers to focus primarily on developing business logic thus speeding up the software development.

Apache Tomcat provides a light weight web container to host SecCharge application. Primarily Tomcat was used because it supports Java and is compatible with Spring MVC and consumes less memory.

And Eclipse is deployed as a fundamental Integrated Development Environment (IDE) for web application development, while Android Studio is used as IDE for Android platform development.

Being open source operating system and Linux distribution based on Debian, Ubuntu is considered as underlying operating system in the SecCharge system.

Representational State Transfer (REST) is an architectural style that specifies constraints to induce desirable properties like performance, scalability and modifiability. These desirable properties make a web service work best on the web. RESTful web services are the web services which implements REST architecture. In SecCharge system, web services are implemented using REST API provided by Spring framework. All HTTP/ HTTPS calls in the application are performed over RESTful web services. And being lightweight data-interchange format, JavaScript Object Notation (JSON) is used.

As Open Charge Point Protocol (OCPP) is an application protocol for communication between wireless charging stations and a central management system, the OCPP is considered as communication protocols between WCSs and the SecCharge CAEV server in our implementation. Being an open protocol, the OCPP would allow wireless charging stations and central systems from different vendors to easily communicate with each other.

For the testbed deployment, the SecCharge CAEV platform uses miniture CAEV. The miniture CAEV is built with remote controlled (RC) car that has been modified using Raspberry Pi 3 along with a Pi camera and I^2C-bus Pulse-width modulation (PWM) controller, namely PCA9685. In order to achieve an automated driving capability, it uses various software libraries including OpenCV (Open Source Computer Vision) and machine learning tools such as Tensorflow and Keras.

Google Map platform is used to compute a distance to be travelled and a time taken for that distance.

6.2 Case Studies and Analysis

In order to provide an efficient automated reservation service, charging parameters should be properly adjudicated. However, determining the charging time may not be straightforward, since it may take long time for full charge. Especially, when the CAEV has limited time for recharging, the required charging time should be determined with pertinent SoC_{tar}.

Furthermore, during daytime, the charging stations in the urban areas may be very demanding. So determining appropriate number of time slots for charging BEVs/CAEVs may be challenging. With efficient allocation of the time slots, the waiting time at the charging stations can be significantly minimized.

For the testbed implementation, we have considered several assumptions in case of the electric vehicles and charging stations.

Since technical details for fully-fledged CAEVs (i.e. Level 4 and 5) are not available till the date, we have determined to utilize the technical specifications of the existing Battery Electric Vehicles (BEVs) for the testbed implementation. Table 2 shows the technical specifications of BEVs that are considered for the testbed implementation.

Table 2: Technical Specifications of BEVs [26]

Make, Model, Year	Battery capacity kWh	Onboard charger kWh	Total range (EPA rating) km	Charging time for full charge h	Avg Fuel consumption rating kWh/100km
Smart fortwo 2017	17.6	7.2	93	3	19.6
Nissan Leaf 2017	30	6.6	172	6	18.6
BMW i3 94Ah 2017	33	7.4	183	5	17.8
Ford Focus Electric 2017	33.5	6.6	185	5.5	19.6
Chevrolet Bolt 2017	60	6.6	383	9.3	17.6
Tesla Model S 75D 2017	75	10	417	12	20.3

Environmental Protection Agency (EPA) has specified a total range (EPA rating) covered by a BEV with full charge, shown in the Table 2.

Charging time for full charge is shown in the Table 2. Basically, the charging time for BEV may depend on following parameters:

- Current SoC level or Energy stored in its battery pack.
- Size of battery pack or Battery capacity.
- On-board charger capacity or Vehicle acceptance rate
- Output of a charging station

For the convenience, plug-in charging outlets such as the International Electrotechnical Commission (IEC) 62196-2 chargers are considered. Typically, in the testbed implementation, we have considered three Level 2 chargers, namely, a) charger with 240V, 3.6kW, 16A; b) charger with 240V, 7.3kW, 32A; and c) charger with 400V, 11kW, 16A.

Case I

Case I depicts the analysis of BEV charging parameters with the given SoC_{tar}.

With the assumption of plug-in charging outlet with 7.3kW, 32A, several sessions of charging process were conducted for the selected BEVs.

Assuming SoC_{th} at 25%, SoC_{tar} is computed such that SoC level reaches at 60%. Then we have obtained various BEV charging parameters including ϵ, $t^{\mathrm{th}}_{\mathrm{tar}}$, τ^{r}, and η. Table 3 shows various BEV charging parameters for the selected BEVs.

Table 3: BEV charging parameters

Make, Model, Year	ϵ, kWh	$t^{\mathrm{th}}_{\mathrm{tar}}$, h	τ^{r}, h	η
Smart fortwo 2017	6.2	0.97	1	4
Nissan Leaf 2017	10.5	1.73	1.75	7
BMW i3 94Ah 2017	11.5	1.73	1.75	7
Ford Focus Electric 2017	11.7	1.94	2	8
Chevrolet Bolt 2017	21.0	3.18	3.25	13
Tesla Model S 75D 2017	26.3	3.93	4	16

It can be seen that eventhough the bigger BEVs yield larger ϵ than the smaller BEVs, the formers need more η than the latters. With the appropriate charging time for different types of BEVs, the system shall be able to efficiently manage the time slots η from various WCSs.

Case II

Case II delineates variation of BEV charging parameters for the specified range. In this case, we have selected two representative BEVs, namely, BMW i3 94Ah 2017 and Tesla Model S 75D 2017.

In order to accumulate similar range, about 100 km, during charging process, SoC_{tar} for BEV should be appropriately computed. It can be observed that determination of α depends on the distance to be travelled.

Assuming intial SoC is SoC_{th}, SoC_{tar} is computed with proper selection of α. Then various BEV charging parameters (i.e. ϵ, $t^{\text{th}}_{\text{tar}}$, η) are obtained for that specified range. Table 4 shows the BEV charging parameters for the specified range.

Table 4: BEV charging parameters for the specified range

Make, Model, Year	SoC_{tar}, %	ϵ, kWh	$t^{\text{th}}_{\text{tar}}$, h	η
BMW i3 94Ah 2017	79	17.8	2.73	11
Tesla Model S 75D 2017	52	19.5	3.13	12

To achieve similar added distance, SoC_{tar} for BMW i3 is significantly higher than that for Tesla Model S. However, BMW i3 requires slightly lesser $t^{\text{th}}_{\text{tar}}$, in turn, η than Tesla Model S.

Case III

Case III illustrates the effect of the charging outlet outputs on the BEV charging parameters.

Appropriate selection of the Level 2 charging outlet may be desirable since with higher charger output, the charging time and the number of time slots can be reduced drastically.

Figure 6 depicts charging time and number of time slots required for various Level 2 chargers.

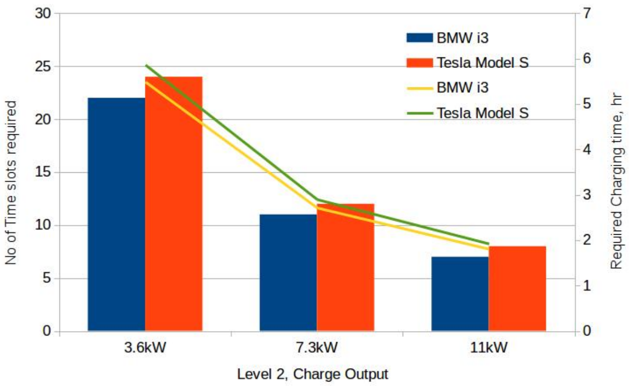


Figure 6: Charging time and number of time slots required for various Level 2 chargers

It can be observed that the charging time decreases with the increase in the charger output. Furthermore, with 7.3kW charger, η for BMW i3 and Tesla Model S are 11 and 12 respectively, whereas with 11kW charger, η for BMW i3 and Tesla Model S are 7 and 8 respectively.

The system shall choose the charging outlet with appropriate charger output for efficient management of the WCSs.

Case IV

Case IV depicts the selection of appropriate targeted SoC level. In order to provide efficient allocation of the time slots at the charging stations, precise computation of SoC_{tar} is essential, which mainly relies upon α.

Determining proper targeted SoC level might be challenging since on one hand, CAEVs do not need to recharge more frequently, but another hand, CAEVs do not have to spend lot of time at the charging stations.

Figure 7 shows the charging time with respect to various SoC_{tar}. With increasing SoC_{tar}, the required charging time increases significantly. In order to provide efficient time slot allocation, SoC_{tar} needs to be computed precisely.

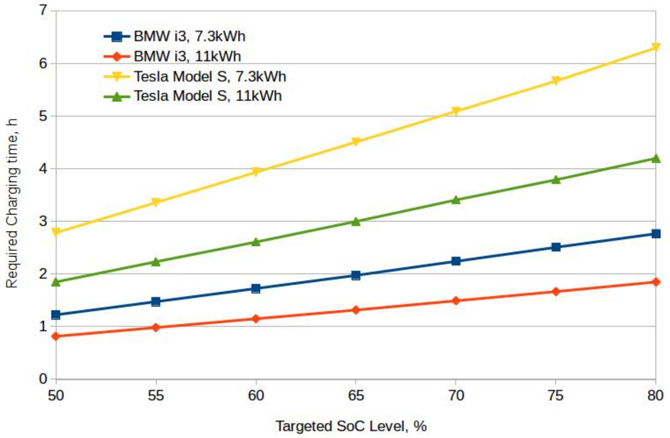


Figure 7: Charging time with respect to various targeted SoC levels

Figure 8 illustrates the energy gained with respect to various SoC_{tar}. The energy gained for Tesla Model S is distinctly greater than that of BMW i3 for all SoC_{tar}. For instance, at $SoC_{\text{tar}} = 60\%$, Tesla Model S has gained 26.3kWh, whereas BMW i3 has gained only 11.5kWh.

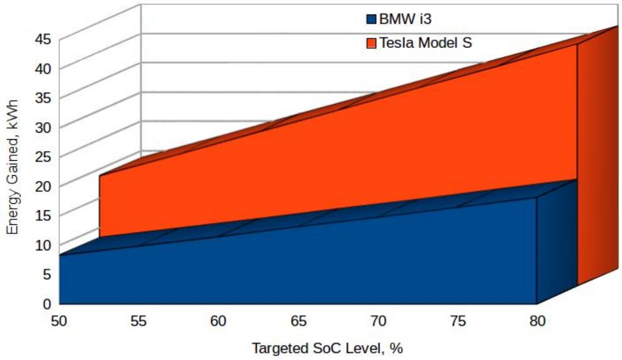


Figure 8: Energy gained with respect to various targeted SoC levels

Figure 9 characterizes the range added with respect to various SoC_{tar}. The range added for Tesla Model S is significantly higher than that of BMW i3 for every SoC_{tar}. For example, at $SoC_{\text{tar}} = 60\%$, BMW i3 has added only 64.4km, while Tesla Model S has added 146.4km.

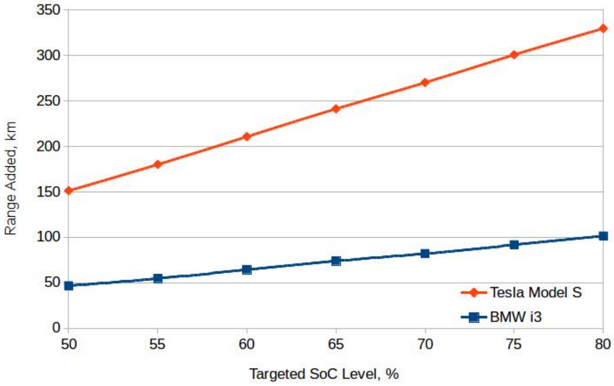


Figure 9: Range added with respect to various targeted SoC levels

7 Conclusions

Connected and Autonomous Electric Vehicles (CAEVs) are getting attention due to the fact that they can provide significant benefits such as improved traffic flow, improved road safety, reduced carbon emission in urban areas and minimized dependency on fossil fuel.

For greater penetration of CAEVs in the smart cites, the deployment of charging facilities in urban areas should be well considered. However, getting information on the availability of charging stations and duration of waiting time at the charging stations is still challenging. In order to manage and allocate the charging station resources from different WCSOs, an efficient and smart CAEV charging management is necessitated. We have designed a system utilizing automated reservation based charging strategies that include effective reservation management and efficient allocation of time slots of wireless charging stations. In this system, charging strategies based on automated reservation are used, which encompass optimum WCS selection in terms of waiting time and charging time as well as scheduling including reservation slot allocation and pre-authorized payment.

The test-bed was built using Backend servers and modified RC cars built on Raspberry Pi. And case studies are carried out along with the analysis to verify the efficient allocation of the time slots in WCSs.

Acknowledgement

This research work is supported by Smart Grid Fund (SGF), Ministry of Energy, The Ontario Government and Canada Research Chair (CRC) Fund, Canada.

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