AN INDEPENDENT PROTOCOL SUPPORTING REAL- TIME CROSS-NETWORK AUTHENTICATION IN ELECTRIC VEHICLES' NETWORK

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ABSTRACT

The absence of charging infrastructure has been highlighted by several researchers as an obstacle in electric vehicle (EV) industry. However, less attention has been drawn to user access to existing charging infrastructure. Therefore, this research investigated the practical methods of increasing accessible charging stations to EV users. EV Service Providers (SP) and EV Networks have been established to provide charging facilities for EV users. However, the business model and method of identifying users have formed a group of closed networks performing in isolation. Despite the availability of charging stations, the isolation of EV networks prevents users from charging their EVs which has created a barrier against the development of EV industry and affected the general acceptance of EVs. Thus, this research aimed at formulating an operational framework which involved a proposed Inter-Service Provider Charging Protocol (ISPCP) that aimed to provide a peer-to-peer communication among networks of charging stations and supports cross-network charging capability for EV users. The framework consisted four phases: review of existing works, development of a protocol, development of a RESTFul WEB API using the protocol, and evaluation of the protocol using the API. To develop the protocol, current state of the art in the networks of EV charging stations was reviewed. In addition, a systematic literature review (SLR) was conducted to investigate the causes and effects of range anxiety and to extract the existing solutions. ISPCP has been implemented, deployed, and tested using a RESTFul WEB API in order to evaluate its feasibility and effectiveness in which performance, response time, and cost were measured and identified as its effectiveness metrics. Findings of the study showed a faster response time of 9.4 seconds which is considered to be a 59.24% improvement when compared to similar protocols. The results obtained in the study provide support for feasibility of ISPCP as it has been proven to increase the number of charging stations accessible to EV users by providing cross-network charging solutions.

ABSTRAK

Ketiadaan infrastruktur pengecasan telah dinyatakan oleh beberapa pengkaji sebagai penghalang dalam industri kenderaan elektrik (EV). Walau bagaimanapun, amat sedikit perhatian yang diberi kepada akses pengguna ke infrastruktur pengisian sedia ada. Oleh itu, kajian ini mengkaji kaedah yang paling praktikal bagi meningkatkan stesen pengecasan yang boleh diakses kepada pengguna EV. Penyedia Perkhidmatan EV (SP) dan Rangkaian EV telah dibentuk untuk menyediakan kemudahan kepada pengguna EV. Walau bagaimanapun, model perniagaan dan kaedah mengenal pasti pengguna telah membentuk sekumpulan rangkaian tertutup yang melakukan pengasingan. Walaupun terdapat stesen pengecasan, pengasingan rangkaian EV telah menghalang pengguna daripada mengecas EV mereka yang telah mewujudkan halangan terhadap pembangunan industri EV dan menjejaskan penerimaan umum EV. Oleh itu, kajian ini bertujuan untuk merumus rangka kerja operasi yang melibatkan Perkhidmatan Protokol Pengecasan Pembekal Antaramuka (ISPCP) yang bertujuan untuk menyediakan komunikasi antara rangkaian stesen pengecasan dan menyokong keupayaan pengecasan rangkaian untuk pengguna EV. Rangka kerja ini terdiri daripada empat fasa: kajian semula kerja sedia ada, pembangunan protokol, pembangunan API WEB RESTFUL menggunakan protokol, dan penilaian protokol menggunakan API. Untuk membangunkan protokol, keadaan semasa dalam rangkaian stesen pengisian EV telah dikaji semula. Di samping itu, kajian literatur sistematik (SLR) telah dijalankan untuk mengkaji punca dan kesan kebimbangan pelbagai dan untuk mengekstrak penyelesaian yang sedia ada. ISPCP telah dilaksanakan, diarah, dan diuji dengan menggunakan API WEB RESTFUL untuk menilai kebolehlaksanaan dan keberkesanannya di mana prestasi, masa tindak balas, dan kos diukur dan dikenalpasti sebagai metrik keberkesanannya. Dapatan kajian menunjukkan bahawa masa maklum balas 9.4 saat, dianggap sebagai peningkatan 59.24% berbanding dengan protokol yang sama. Dapatan yang diperoleh dalam kajian ini memberikan sokongan untuk kelayakan ISPCP kerana telah terbukti bahawa terdapat peningkatan jumlah stesen pengecas yang dapat diakses oleh pengguna EV dengan menyediakan penyelesaian pengecasan rangkaian silang.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
API	-	Application Programming Interface
B2B	-	Business-to-Business
BEV	-	Battery Electric Vehicles
CAN	-	Controller Area Network
CI	-	Charging Infrastructure
CP	-	Charge Point
CD	-	Continuous Deployment
CS	-	Central System
DC	-	Direct Current
DDD	-	Domain Driven Design
DevOps	-	Development and operation
DSO	-	Distribution System Operator
EMP	-	Electric Mobility Provider
EV	-	Electric Vehicle
EVSE	-	Electric Vehicle Supply Equipment
HEV	-	Hybrid Electric Vehicle
ICT	-	Information and Communication Technology
ISPCP	-	Inter-Service Provider Charging Protocol
IT	-	Information Technology
LAN	-	Local Area Network
OCPP	-	Open Charge Point Protocol

OCHP	-	Open Clearing House Protocol
OSCP	-	Open Smart Charge Protocol
PDU	-	Protocol Data Unit
PHEV	-	Plug-In Hybrid Electric Vehicles
PLC	-	Power-Line Carrier
REST	-	Representational State Transfer
RFID	-	Radio Frequency Identification
SDLC	-	Software Development Life Cycle
SDO	-	Standard Development Organization
SLR	-	Systematic Literature Review
SOA	-	Service Oriented Architecture
SOAP	-	Simple Object Access Protocol
SOP	-	Standard Operational Procedure
SP	-	Service Provider
UDDI	-	Universal Description, Discovery, and Integration
V2G	-	Vehicle-to-Grid
WSDL	-	Web Services Description Language

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In transportation industry, conventional vehicles which uses petroleum as a source of energy will soon face a critical world-wide issue – Shortage of Petroleum; and as an alternative, Electric Vehicles (EV) come into play. EVs brought the chance of reducing dependency on petroleum by using renewable sources of energy. They also can be considered as a network of large, flexible, distributed power storages capable of providing energy to the grid. General acceptance of EV requires universality in different components of this network which will be achieved by a set of standards prepared by Standard Development Organizations (SDO). Currently there are several business operators providing charging stations for EVs and offering features such as online billing and reporting for EV Owners (EVO). But these so-called "networks of EVs" are suffering from isolation. Therefore, this research focuses on a solution to provide a standard way of communication among networks of EV charging stations.

1.2 Background of Study

Current transportation mechanisms are mostly powered by oil-based fuels. Regarding the problems caused by fossil fuels such as cost and air pollution, and to reduce dependency on oil, alternative transport mechanisms are gaining attention. One of the alternatives is EV (Tate, Harpster, & Savagian, 2008; Vliet, Brouwer, Kuramochi, Broek, & Faaij, 2011).

The increase in the number of EVs demands more Charge Points (CP) in both public and private areas; because the availability of charging stations is a significant factor in general acceptance of EVs (Chung, 2014; A M Foley, Winning, & Gallachoir, 2010; Römer, Schneiderbauer, & Picot, 2013). CP is an important entity in the future power grids. Besides providing physical charging facilities it can be considered as a communication interface for exchanging information between different entities of a supply network and network of EVs (Haidar, Muttaqi, & Sutanto, 2014; Winkler et al., 2009), capable of providing data for monitoring and scheduling of energy distribution.

EV, Electric Vehicle Supply Equipment (EVSE), CP, Power Grid, and Service Providers (SP) are key components of a Charging Infrastructure (CI) (Vaidya, Makrakis, & Mouftah, 2014). A successful deployment of EVs requires unified platforms and frameworks. Nowadays, SDOs play a significant role in unification and monitoring of new technologies based on common agreements of governments, stakeholders, industry experts, and academic researchers (Brown, Pyke, & Steenhof, 2010; A M Foley et al., 2010). A few terminologies, methodologies, and different set of requirements can be extracted from these standards which have been used by EV manufacturers, EVSE and CP manufacturers and SPs (Aoife M Foley, Winning, & Ó Gallachóir, 2010).

The importance of universality in EV industry can be highlighted in researches on Smart Grid and Vehicle-to-Grid (V2G) technology. The smart grid is emerging as a convergence of information technology and communication technology with power system engineering (Farhangi, 2010) to control and monitor the power flow in grids. As its basic role, smart grid provides full visibility and control over the utility assets with a self-healing approach. It is capable of remote maintenance, predictive and detective functionalities for maintaining and repairing grid as well as providing pricing system for end users to let them decide when to charge (Decker, 2012; Farhangi, 2010; Singhal & Saxena, 2012). V2G is a component of smart grid in which energy status of EV is collected periodically for power management and the energy can be sent back on grid's demand. This will provide a broad array of advantages and opportunities to both EVOs as well as energy suppliers (Bakker, 2011; Jansen, Binding, Sundstrom, & Gantenbein, 2010; Kumar & Udaykumar, 2013; Liu, Ning, Zhang, Xiong, & Yang, 2014).

Having a Smart Grid with enough intelligence to provide V2G operations and other dynamic real-time responses, needs a unified network of EVs and EV charging infrastructures capable of sending and receiving information throughout universal communication interfaces among different entities of the infrastructure. Therefore, SAE and ISO, as two major SDOs in EV industry, have provided a set of standards targeting the physical connection between EV and CP along with technical details on dimension and power flow. However there still exists a few different charging types and charging levels or modes, but SDOs are playing their roles to achieve a standard combo connection to be used as a universal charging type with the ability to satisfy requirements of different charging modes.

On the other hand, SPs require the EVOs to subscribe to their networks to use CPs and other facilities provided by the SP. This subscription requirement has caused isolation in the networks of EVs, because each network will only provide services to their subscribed users. However, the subscription is required because there needs to be a control over energy consumption of EVs and planning of electricity distribution. To monitor and predict EV charging patterns, energy distribution strategy, and smart charging, the data collected from subscribed EVOs is required.

The subscription requirement and the necessity of communication among networks of EVs, brings up the research interest on interoperable communication protocols; which in fact, is the focus of the current research.

Currently in Malaysia there are a few SPs and EV industry is in a premature stage. Comparing to developed countries, the EV industry in Malaysia is in a young stage. Unless this technology is widely developed and publicly accepted, it will not draw investors' attention to invest on this technology. However the acceptance of EVs in Malaysia is related to several parameters such as social influences, performance attributes, financial benefits, environmental concerns, demographics, infrastructure readiness and government interventions (Sang & Bekhet, 2015). Besides, driving habit and backed up traffic jams in Malaysia needs to be taken into account while discussing development of EVs. Although EVs have major environmental benefits, there are magnificent differences between them and ICE engines. Among these differences, travel range and availability of power source are considered as major obstacles against smooth development of EVs. Thus, since EVs are new in Malaysia, absence of retail infrastructure in public areas makes people reluctant to use them.

1.3 Statement of Problem

There are several manufacturers of CPs and different SPs that install and maintain them. A group of EVOs registered under the same SP to use their facilities are considered as a network. EVs, EVOs, CPs, and CS are main components of each charging network. Currently there is a set of standard communication mechanism between EV and CP, in terms of hardware, power flow and data transactions which are being controlled by major SDOs. Also, there is a communication protocol between CP and CS named Open Charge Point Protocol (OCPP); which is not officially announced as standard, but it is accepted and being followed by industry.

Generally, before EVO can start charging, the operation needs to be authorized by CS. Radio Frequency Identification (RFID) tags are the common authentication devices which have been used in different industries for decades. Considering OCPP as the communication protocol between CP and CS, the CP will send *Authorize.req* Protocol Data Unit (PDU) along with the *idTag* as parameter to CS. *idTag* is the RFID tag code which needs to be verified against the information on the server. Upon receiving of an *Authorize.req* PDU, the Central System responds with an *Authorize.conf* PDU. This response will indicate whether the *idTag* is accepted by the CS or not. After the authentication, the CP will unlock the connector and EVO can start charging. According to OCPP, each CP will individually communicate with the CS which is configured to. Therefore, the relationship between CP and CS is many-to-one (many CP to one CS). While there are several standards and protocols which control the communication between "*EVO and CP"* and "*CP and CS"*, yet these communications are controlled by SPs which will only authorize the EVOs who are registered in their network. In another word, CPs are not configured to contact any CS other than the one in their network. As a result, EVOs are not able to use CPs of other SPs to charge their EV.

Insufficient number of charging stations and the fact that the EVOs are not able to use cross-network CPs will cause "Range Anxiety" among EVOs. Range anxiety, which has been shown to be a significant obstacle to market acceptance of EVs, is the term to describe EVOs' concern of being left on the road with an empty battery where there is no charging station at all or there is not any station of the SP in which they have registered (Bakker, 2011; Dong, Liu, & Lin, 2014; Mal, Chattopadhyay, Yang, & Gadh, 2013; Mültin, Gitte, & Schmeck, 2013; Tate et al., 2008).

Considering range anxiety as a barrier against user acceptance of EVs, and the fact that sooner or later several SPs will provide public and private charging stations in Malaysia, and since the keys to success in management and business is to identify and prevent problems before they occur (Roberto, 2009), the earlier this issues is being resolved, the faster EV industry can grow.

This emphasizes on necessity of interoperable protocols. These protocols will use different software architectural approaches to facilitate communication among SPs. SOAP or REST architecture are among the methods of communication. But current interoperable protocols require an interface company or a central database to hold and verify the users. In another words, this communication is not direct.

Considering the capability and flexibility of REST architecture, SPs can communicate directly if there is a standard protocol to control the rules and requirements of this communication. With a direct communication, users of any network of EVs will be able to use any CP. However, the billing process will be a challenge. In the current interoperable protocols (such as OICP) the interface company will control the billing. By reviewing the business process of current EV networks, after the charging process, billing and transaction details will be sent for the users. But if the user is using a CP from another network, the bill needs to be sent to the original SP and the billing process needs to be handled by that SP.

This research is addressing user authentication and billing problems to provide direct communication among different networks of EV charging stations.

1.4 Research Questions

Based on the identified problem, the main question of the research is "*How to reduce range anxiety among EVOs?"* To answer this question, following supporting questions can be highlighted:

1. What is the current situation, challenges, and issues in network of EV charging stations?

2. To provide a standard protocol for communication between SPs, what aspects of communication need to be immediately addressed?

3. How effective is the protocol in connecting the SPs and providing the possibility of cross-network utilization of CPs by EVOs?

1.5 Objective of the Study

The main purpose of this study is to develop a protocol for communication between different SPs. This communication will allow EVOs to charge their EVs in any charging station, regardless of the SP to which they have subscribed. In order to achieve this, the following objectives are identified:

1. To review state of the art in networks of EV charging stations and their solution architecture.

2. To develop a standard protocol providing real-time cross-network authorization capability.

3. To develop a software service using the proposed protocol

4. To evaluate feasibility and effectiveness of the proposed protocol using the developed software services.

1.6 Scope of the Study

The focus of the proposed study is on the development of a protocol to control the communication between SPs in order to allow EVOs to use any CP regardless of the SP. To do so, current state of the art in EV industry is reviewed. Basic information about EV, EVSE, CP and the communication mechanisms among them has formed the initial stage of this research. However, the details of power grid, smart grid, V2G, energy distribution, energy supplier, and also the internal technology of EV, battery, and CP are out of scope of this study.

Interoperable protocols need to cover a vast area of business and functionality. Features such as CP reservation, pricing and cost estimation prior to charging, billing, credit management, etc. are not covered in this research due to lack of infrastructure readiness in Malaysia. The focus of the proposed protocol is on authorization of EVOs.

To test the protocol and monitor the communication between SPs, a web service is developed following the rules and procedures mentioned in the protocol. The service is deployed on two servers with unique user information. This service only communicates between these two servers. To visualize the sent and received data, and to call service methods, Postman[1] is used and Microsoft Visual Studio is used to test the performance of the service.

1.7 Significance of the Study

Lack of a standard approach in communication between entities of EV charging networks has caused the problem of multiple manufacturers with different communication methodologies and a group of isolated networks. This has forced user to register in several networks and carry multiple authentication devices. Besides, a unified network of EVs is necessary to have features such as smart charging, V2G, trip forecasting, and other Business-to-Business (B2B) facilities that require information on EVs and their consumption patterns.

Insufficient number of charging stations and the fact that EVOs are not able to use any CP other than the one managed by their network, will bring up range anxiety among EVOs. This research proposes a protocol to standardize a direct communication between SPs of different networks of charging stations. Using this protocol, the SPs will be able to authorize users from any network. As a result, number of CPs available to EVOs will increase. Once the users do not need to worry about availability and accessibility of CPs during their trips, their range anxiety level will decrease.

Beside the possibility of direct communication, the performance of the communication is also important. The protocol proposed in this study provides a peer-to-peer communication among different SPs. Since the charging requests will be distributed among different servers, the responses consume lesser time.

[1] Postman is a Google Chrome app for interacting with HTTP APIs. It presents a friendly GUI for constructing requests and reading responses (https://www.getpostman.com/postman)

1.8 Structure of the Thesis

The thesis is organized in six chapters. All chapters are interrelated to one another. Thus, the chapters should not be read in isolation. Chapter 1, 2, and 3 introduce the topic of the research, discuss the related literatures, and plan the processes of conducting the research. Besides general definitions, findings of a systematic literature review (SLR) and the necessity of a standard communication method among different EV networks are discussed in Chapter 2. Based on the findings of the SLR a comparative analysis has been done on the current communication protocols and represented in this chapter as well. Chapter 4 describes the proposed protocol in detail. In Chapter 5 the details of implementation and the results of testing the protocol are presented. Conclusion of the research forms the last chapter of this thesis.

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