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WAVE 4 V2G: Wireless access in vehicular environments for Vehicle-to-Grid applications

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A B S T R A C T

Plug-in Electric Vehicles (EVs) are expected to greatly reduce the carbon emissions from surface transport if they are widely used and efficiently charged. One of the main limitations of EVs is their limited range and relatively long recharging times. This limitation is closely associated with the current battery technologies used in the EVs. In order to efficiently utilize the EVs, their charging schedules and locations must be effectively integrated within the smart grid. Real-time and reliable integration of EVs with the smart grid could solve problems related to demand response, cost and time of charging. In this paper, we present an overview of the state-of-the-art in Wireless Access in Vehicular Environments (WAVE) for Vehicle-to-Grid (V2G) applications and highlight the main challenges associated with implementing WAVE in V2G applications. We present two IEEE 802.11p-based Quality of Service (QoS) schemes to facilitate the interaction between the smart grid and EVs, namely, QoS scheme for Charging EVs (QCEV) in a smart grid environment and a Channel Access Control (CAC) scheme. Unlike conventional contention based distributed QoS approaches used by the IEEE 802.11p MAC protocol, both of the QCEV and the CAC schemes provide centralized QoS differentiation in situations where urgent EV battery charging is required. The centralization is done at the Access Point (AP) which takes an informed decision on which EV should receive highest priority to access the channel based on the individual EV battery levels, and also based on the availability and cost of the electricity at different locations.

1. Introduction

The availability of charging stations and the power required to charge multiple plug-in Electric Vehicles (EVs) at the same time is a major concern for electrical utility operators and EV owners. For instance, in today's power grid, the cost of electricity is dependent on the time of use and the instantaneous load on the grid. This process allows the "smart grid" to manage the load on a micro-level, which is achieved by enabling reliable and real-time communication between EVs and the smart grid so that the load and the generation can be scheduled and distributed in an optimum manner. Real-time and reliable Vehicle-to-Grid (V2G) communication can solve problems related to load issues resulting from non-synergistic EV recharging processes. The collaboration is achieved by allowing the smart grid to match generation to electricity use and manage loading on different EVs charging infrastructures in a real-time manner.

Efficient wireless communication and data management in V2G environment calls for a reliable and low communication latency integration between these two sub-systems. Quality of Service (QoS) is one of the main determining factors for successful V2G integration. In a wireless communication environment, QoS can have several meanings. It can represent the capability to provide assurance that the service requirements of a specific application can be met. QoS can also be defined as the ability of the network to adapt to specific classes of data. In mobile wireless environments, QoS is a challenging issue due to the highly dynamic nature and dense communication environment between EVs and Access Points (APs).

V2G communications involve vehicular nodes (in this case EVs) and APs. In V2G communication, there are several technologies that can support this communication, such as IEEE 802.11 (WiFi), IEEE 802.16 (WiMAX), and Dedicated Short Range Communications (DSRC). Some V2G applications may require Vehicle-to-Vehicle (V2V) communication. For example, the exchange of charging station information among EVs on a road. In this case, vehicles form a Vehicular Ad hoc Network (VANET).

In V2G communication, the IEEE 802.11p standard is emerging as a popular standard for such applications. The IEEE 802.11p standard is an amendment to the IEEE 802.11 standard which was

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proposed for Wireless Access in Vehicular Environments (WAVE) [1]. The standard is basically designed to enable communication in mobile environments e.g. V2V and V2I communication. The IEEE 802.11p physical layer is similar to that of the IEEE 802.11a standard. However, to cope with the highly mobile environment, the bandwidth of the IEEE 802.11p is reduced to the half of the IEEE 802.11. Its Medium Access Control (MAC) protocol is inspired by the MAC of the IEEE 802.11e standard [2] with some modifications to make it more suitable for mobility (e.g. the use of 4 ACs instead of 8). Similar to the IEEE 802.11e, the IEEE 802.11p uses the Enhanced Distributed Channel Access (EDCA) mechanism. The EDCA mechanism allows the high-priority traffic to have a higher chance of acquiring the channel access and being transmitted compared to the low-priority traffic. However, the QoS differentiation used in both standards is based on the traffic type which is predefined by the application layer.

The integration of EVs and the smart grid in applications such as EV charging coordination and control, demand response and ancillary services requires real-time collaboration between the smart grid through the APs and the EVs to make decisions in a reliable and real-time manner. Conventional QoS approaches used in the IEEE 802.11p standard may not be efficient for applications that are highly variable and change in seconds, for example, the availability of charging stations and utility load is expected to be extremely dynamic. Therefore, conventional QoS differentiation approaches may affect the entire energy distribution and control process and even affect the overall network performance especially in dense EV deployment.

In this paper, we present an overview of state-of-the-art in WAVE for V2G applications and highlight the main challenges associated with implementing WAVE for V2G applications. We then present two IEEE 802.11p-based QoS schemes that facilitate the interaction between the smart grid and EVs. These schemes are: QoS scheme for charging EVs (QCEV) in a smart grid environment [3] and a Channel Access Control (CAC) scheme [4]. These schemes provide QoS differentiation in V2G scenarios. Unlike conventional contention based distributed QoS approaches used by the IEEE 802.11p MAC protocol, the QCEV and the CAC schemes provide centralized QoS differentiation in situations where immediate EV battery charging is required. The centralization is done at the AP which takes an informed decision on which EV should receive highest priority to access the channel based on the individual EV battery levels, and also based on the availability and cost of the electricity at different locations. In this paper, we compare the performance of the QCEV and the CAC scheme with each other and with the default IEEE 802.11p standard. We also introduce more comprehensive evaluations of the two schemes. Our simulation results show that the presented schemes outperform the IEEE 802.11p standard.

The rest of the paper is organized as follows. In Section 2, we present the challenges of implementing WAVE in V2G applications. In Section 3, we present the related work. In Section 4, we present an overview of the IEEE 802.11p MAC protocol. In Section 5, we describe our scenario. In Section 6, we present our IEEE 802.11p-based QoS schemes. In Section 7, we present simulation results and analysis and finally we conclude our work in Section 8. Table 1 shows the list of acronyms used in this paper.

Table 1
Table of acronyms.

Acronym	Definition
EV	Electric Vehicle
WAVE	Wireless Access in Vehicular Environment
V2G	Vehicle-to-Grid
QoS	Quality of Service
QCEV	QoS scheme for Charging EVs
CAC	Channel Access Control
AP	Access Point
DSRC	Dedicated Short Range Communications
V2V	Vehicle-to-Vehicle
VANET	Vehicular Ad hoc Network
RSU	Road Side Unit
PHEVs	Plug-in Hybrid Electric Vehicles
ITS	Intelligent Transportation Systems
V2I	Vehicle-to-Infrastructure
IoE	Internet of Energy
SoC	State-of-Charge
G2V	Grid-to-Vehicle
WMN	Wireless Mesh Network
DORA	Dynamic Online Routing Algorithm
AC	Access Category
AIFS	Arbitration Interframe Space
TXOP	Transmission Opportunity
SIFS	Short Interframe Spacing
CW	Contention Window
CCH	Control Channel
SCH	Service Channel
UP	User Priority
WSM	WAVE Short Message
SA	Service Advertisement
WBSS	WAVE Basic Service Set

2. Background and implementation challenges

Reliable and real-time two-way communication in V2G applications are two of the major issues that need to be addressed to facilitate a real-world implementation of an efficient V2G communication system. Due to the nature of the V2G environment and the challenges for system deployment, WAVE needs to consider several issues. In addition to that, in V2G communication, QoS is important to guarantee the normal operations of the smart grid. These challenges can be summarized below. In this section, we highlight the main V2G implementation challenges and present work published in the literature to address these challenges in general VANET environment.

2.1. Mobile environment

Obtaining information about real-time charging pricing and peak times in addition to en-route charging station reservation in highly mobile environment is one of the main challenges of implementing WAVE in V2G applications. Furthermore, V2G application introduces a new class of applications, e.g. EVs can be used regulate the frequency, peak shaving and other ancillary services in the smart grid. In such applications EVs need to initiate and terminate the communication with APs while they are still within the APs's transmission range. The integration of EVs into the smart grid to satisfy such application requirements is not an easy task.

The IEEE 802.11p standard is required to handle not only communication at high speed but also in a real-time fashion. In most scenarios, the IEEE 802.11p standard must handle the two-way communications before the communicating EVs leave the coverage area of their AP. In addition to that, mobile EVs environment makes reliable transmission in smart grid more challenging.

Charging information of EVs is exchanged with the AP through wireless transmission to enable real-time decision making and to improve the EV charging efficiency. However, in a mobile environment, the charging of an EV is becoming more demanding and challenging due to the mobility, changing power levels and limited number of APs on the road. Furthermore, in a smart grid environment, QoS communication is essential for the entire system to adapt system behavior and provide real-time pricing. Communication delay is critical for EV charging process decision making, online reservation and exchange of information with the smart grid.

There are many publications that discuss mobile environments in VANETs [5–7]. An et al. [6] have studied the behavior of packet