A QoS Scheme for Charging Electric Vehicles in a Smart Grid Environment

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Abstract—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 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 propose a Quality of Service (QoS) scheme for Charging EVs (QCEV) in a smart grid environment. The proposed scheme provides centralized QoS differentiation to EVs that are communicating with an Access Point (AP) in situations where immediate EV battery charging is required. Our simulation results show that QCEV could significantly improve the performance of the wireless communication network especially in dense deployments.

Index Terms—IEEE 802.11p, smart grid, QoS, End-to-end delay, throughput, electric vehicles.

I. INTRODUCTION

Electric Vehicles (EVs) and Plug-in Hybrid Electric Vehicles (PHEVs) are considered as “green” as the electricity used to charge their batteries [1]. EVs available in the market today can have an average of up to 160 kilometres per charge [2]. Furthermore, there is a trade-off between battery cost and additional range, which explains the high cost of EVs that provide extended range. Therefore, the availability of charging stations, cost and time of charging the EVs are considered the main reasons why EVs are not widespread in today’s market.

The power required to charge multiple EVs at the same time is a major concern for electrical utility operators. For example, the cost of electricity is very much dependent on the time of the day and the instantaneous load on the grid. There is a necessity for a “smart grid” to manage the load on a micro-level by enabling communication between EVs and electricity suppliers so that load and generation can be scheduled in an optimum manner. This integration and communication could mitigate load issues resulting from recharging batteries, where the smart grid could match generation to electricity use and manage loading on different EVs charging infrastructures. Therefore, the smart grid becomes a feasible solution to multiple problems which enables dynamic real-time integration of information exchange between the electricity network and the electrical transportation system [1].

Efficient communication and data management between the smart grid and EVs to optimize charging cost and durations calls for a reliable integration between these two independent systems. The integration reliability of these systems depends on the ability of the communication system to provide real-time and Quality of Service (QoS) guarantees. QoS is a challenging issue especially in wireless communication environments due to the highly dynamic nature and dense communication environment between EVs and Access Points (APs) (i.e. the roadside units).

IEEE 802.11p [3] is a wireless standard based on the IEEE 802.11 standard designed for Wireless Access in Vehicular Environments (WAVE). It proses enhancements required to support Intelligent Transportation Systems (ITS) applications. Therefore, the IEEE 802.11p standard is intended to improve the transportation in terms of safety, mobility and impact on the environment. The IEEE 802.11p is recently being used in a preferred standard to integrate ITS with the smart grid. IEEE 802.11p MAC protocol is based on the IEEE 802.11e MAC protocol [4] which uses different measures at the MAC layer to enforce QoS guarantees to different traffic classes (known as Access Categories (ACs)).

The integration of the ITS and the smart grid system in applications such as EV charging optimization requires real-time collaboration between the AP and the EVs to make proper QoS differentiation decisions. Conventional QoS approaches used in the IEEE 802.11p standard my not be efficient for such applications, since an uninformed QoS differentiation decision by one EV may lead to affecting the entire energy optimization process or even affecting the overall network performance especially in dense networks.

In this paper, we propose a QoS scheme for charging EVs (QCEV) in a smart grid environment. Unlike conventional contention based distributed QoS approaches used by the IEEE 802.11p MAC protocol, the QCEV scheme provides 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.

The remainder of this paper is organized as follows. In Section II, we present the related work. In Section III, we present an overview of the IEEE 802.11p MAC protocol. In Section IV, we describe our scenario. In Section V, we describe the QCEV scheme. In Section VI, we present the simulation results and the analysis. Finally, in Section VII we conclude the paper.
II. RELATED WORK

In the past few years, the integration of EVs and PHEVs with the smart grid has been the focus of several research papers and technical reports. EVs charging infrastructure in a smart grid environment has been extensively discussed in [5]. Furthermore, the impact of the number of the connected EVs on the stability of the electrical system has been presented in [6]. In addition to that, automated energy management between EVs and the smart grid has been studied, where multiple objective functions have been formulated to maximize customer benefits and maintain acceptable power grid operation levels [7].

The requirements of the data communication systems used in smart grid has been widely discussed in the literature. A comprehensive overview of smart grid communication needs has been highlighted in [8], the report has discussed the challenges and opportunities in implementing EVs in the smart grid. The use of real-time wireless networks for the automation of the smart grid has been widely discussed in the literature [9] and [10].

In [11], the authors have presented an overview of the electrification of transportation where they have considered different aspects of the integration of the EVs and PHEVs with the smart grid including some communication requirements. However, the authors have not considered the possibility of using either the IEEE 802.16 and the IEEE 802.11p protocols as possible communication protocols for this integration. The consideration of the IEEE 802.11p protocol for the integration of the ITS with the smart grid is of considerable importance since the IEEE 802.11p protocol is specifically designed to provide wireless access in vehicular environments. Furthermore, one of the main features of the protocol is that it can provide QoS which is considered as one of the main requirements identified in [8].

The consideration of the IEEE 802.11p protocol in critical applications has been extensively discussed in the literature [12], [13] and [14]. Furthermore, several studies have considered the use of analytical models to evaluate the performance of IEEE 802.11p-based networks [15] and [16] and the use of simulation model have also been considered in [17] and [18]. The use of a centralized provisioning mechanism to provide QoS differentiation to EVs communicating to an AP in a smart grid environment has not been considered in the literature. Furthermore, the concept of enforcing real-time communication between EVs and the smart grid to optimize the charging schedule and location has not addressed in such environments.

III. AN OVERVIEW OF THE IEEE 802.11p MAC PROTOCOL

All of the IEEE 802.11 standards adopt a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol to avoid collisions. However Collision Avoidance (CA) mechanisms could vary based on different versions of the standard. In the IEEE 802.11p protocol [3], there are two choices for MAC protocol: the Distributed Coordination Function (DCF) used in the general IEEE 802.11 protocols and the Enhanced Distributed Channel Access (EDCA) utilized by the IEEE 802.11e protocol [4]. The DCF mechanism is contention-based and is always used for a Basic Service Set (BSS) and Independent BSS (IBSS). The IEEE 802.11 protocol can also use the Point Coordination Function (PCF) which is a contention-free option to provide centralized operation. To provide QoS, the IEEE 802.11e protocol use a new coordination function called the Hybrid Coordination Function (HCF) with two types of channel access mechanisms, EDCA and HCF Controlled Channel Access (HCCA). Therefore, in order for the IEEE 802.11p MAC layer to provide QoS to important safety and delay-critical messages, the application of normal IEEE 802.11 MAC layer becomes insufficient. Therefore, the IEEE 802.11p MAC layer is uses EDCA mechanism to provide QoS.

In IEEE 802.11p similar to IEEE 802.11e, the frame with the highest priority gets access to the channel first. To use priority, IEEE 802.11e MAC uses a Traffic Identifier (TID), which is a value in a MAC Service data unit (MSDU) ranging from 0 to 15. An MSDU of value from 0 to 7 indicates user priority of the frame, where 0 is the highest priority. Furthermore, an MSDU of value from 8 to 15 identifies the traffic stream for which the frame belongs to [19]. In addition to that, the IEEE 802.11e uses the Transmission Opportunity (TXOP), which is a bounded time interval when a Station (STA) is permitted to send a series of frames which define when STA can transmit and what the maximum transmitting duration is (TXOP limit). A TXOP obtained from EDCA contention is called EDCA TXOP [3]. The value of a TXOP limit is determined by the AP, according to the rules of the channel access schemes and is informed to all STAs through beacons. Therefore, the use of TXOP makes the transmission time for each STA controllable and predictable. As mentioned earlier, there are eight respective values ranging from 0 to 7 of User Priority (UP) in each MSDU. The MAC layer categorises each frame into its corresponding AC according to its UP value. The AC behaves as a flag for the common set of EDCA parameters adopted by STAs for channel contention. There are four AC defined by each EDCA, these are namely: $AC_{BK}$ (Background), $AC_{BE}$ (Best Effort), $AC_{V1}$ (Video) and $AC_{VO}$ (Voice traffic) [20].

A. EDCA for 802.11p

In addition to the adoption of the IEEE 802.11e EDCA in the IEEE 802.11p protocol, the protocol also uses additional enhancement due to the nature of IEEE 802.11p applications. One of the major enhancements at the MAC layer is the use of multi-channel operation. These different channels (i.e Control Channel (CCH) and Service Channel(SCH)) provide different traffic categories to achieve additional QoS guarantees to critical traffic.

Both the CCH and SCH provide four ACs labelled from AC[0] to AC[3]. Whereas AC[3] has the highest priority and AC[0] has the lowest priority. Table I shows examples of different ACs with typical application requirements in the IEEE 802.11p protocol. In the IEEE 802.11p, for delay critical
TABLE I
DIFFERENT ACs AND APPLICATION REQUIREMENTS

<table>
<thead>
<tr>
<th>Access Category</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC[3]</td>
<td>Emergency information</td>
</tr>
<tr>
<td>AC[2]</td>
<td>Information broadcasted by vehicles</td>
</tr>
<tr>
<td>AC[1]</td>
<td>Inter-vehicle information exchange</td>
</tr>
<tr>
<td>AC[0]</td>
<td>Non-safety-related connections using SCHs</td>
</tr>
</tbody>
</table>

From Fig. 1, we notice that during CCH time channel activities on SCH are terminated and during SCH activities CCH activities are terminated [21].

IV. SCENARIO DESCRIPTION

There are multiple options to charge EVs [1]. The choice of one charging option over the other depends very much on the cost of charging, the availability of the charging, time required to charge and the distance from the EVs to the charging stations. In this scenario, we assume that there are three options to charge the EV. In our scenario we categorise these options based on cost, availability and service time. Therefore, we assume that the Battery Change Station (BCS) is the best option followed by the fast charging station then finally charging at home as shown in Fig. 2.

In our scenario, we assume that there are (N) EVs on the road at any moment of time and that these EVs travel at an average speed of 60 km/h. Furthermore, all of these EVs have established a link with one or more APs (within their transmission range) using the IEEE 802.11p protocol as shown in Fig. 2. These EVs communicate with the AP to exchange various safety information and also to exchange available charge information. Each AP is connected to a Smart Grid Server (SGS) to acquire information for optimizing the cost of charge (CC), distance to charging locations (DC) and time to charge (TC).

During the initial network set-up phase, all EV send their State of Charge (SoC), distance to arrival (d) and their destination (D) to the AP. The AP responds by providing optimum charging options to these EVs and also provide QoS differentiation to an EV that requires immediate charging. The optimization of charging options is done in a near real-time manner at the AP by communicating with the SGS. The EV driver can decides which option to take and then makes the reservation to charge at the selected option through the AP.

V. THE QCEV SCHEME

The QCEV scheme provide QoS differentiation to EVs that require immediate charging due to the low battery level.

traffic, more time is assigned to CCH, and for regular traffic more time is assigned to SCH [3]. Therefore, a balance between the time allocated to CCH and SCH channels is is required depending on the traffic type and the environment [21]. In addition to different ACs and channel type, the size of the Contention Window (CW) (where \( CW_{\text{min}} \) is 15 and \( CW_{\text{max}} \) is 1023) along with the combination of the backoff window are used to enforce different QoS guarantees [3].

B. Multi-Channel Operation

The IEEE 802.11p protocol divides the MAC layer of the Dedicated Short Range Communication (DSRC) into two sub-layers. The upper MAC layer (defined by IEEE 1609.4 standard), which uses channel coordination, channel routing and UP. The lower sub-layer which is responsible for wireless medium access. The standard provides guidelines for a single STA under one CCH and SCH by providing alternating channel access mechanism. The combination of these alternating CCH and SCH intervals is referred to as Sync interval [3]. The CCH and SCH intervals are 50 ms long each [3], with a guard interval of 2 ms to separate them.

Network management messages such as WAVE Short Message (WSM) and Service Advertisements (SAs) are exchanged over CCH. Therefore, initially all STAs are required to instantaneously listen to the CCH to achieve synchronisation and network management. This listen period has to be considered when distributing the channel allocation between the CCH and the SCH channels especially in heavy data transmission [3].

The IEEE 1609.4 standard provides four possible access choices, these namely are ; continuous, alternating, immediate and extended channel access [22]. These different channel access choices depend very much on the application traffic and the QoS requirements. Fig. 1 shows the four channel access mechanisms defined in [3].
available at the time of link establishment with the AP. The aim of QCEV scheme is to give the EV with critical battery charge higher probability in accessing the channel and hence reducing the end-to-end delay and increasing the throughput.

The QCEV scheme works as follows; a group of \( N \) EVs within the WAVE Basic Service Set (WBSS) broadcast their charge status to the AP during the network association phase using the normal DCF procedure described in [3]. At the same time, the AP has access to available charging infrastructure and current charging costs through communicating with smart grid servers. After the association phase is complete, the AP evaluates the available charge in all EVs in its WBSS and then decides which EV will have higher priority to have channel access.

The QCEV scheme modifies the default prioritization of transmission in EDCA which is implemented by a Arbitrary Inter-Frame Space (AIFS). AIFS is an extension of the backoff procedure in DCF by assigning new AIFS values for different ACs. The duration AIFS[AC] is a duration derived from the AIFS Number (AIFSN) and is given in the following relation:

\[
AIFS[AC] = AIFSN[AC] \times Slot_{Duration} + SIFS_{Duration}
\]

where, \( AIFSN[AC] \) is set by each MAC protocol, \( Slot_{Duration} \) is the duration of a single slot, and \( SIFS_{Duration} \) is the length of SIFS. and the Backoff Duration (BD) is given by:

\[
BD = CW_{min} \times Slot_{Duration}
\]

where, \( CW_{min} \) is the minimum CW described in [st].

According to [3], different ACs are associated with different AIFSNs. Therefore, by using equations (1) and (2), we see that the AC with a smaller AIFS has higher priority to access the channel. Furthermore, different CW sizes are assigned to different ACs which is also used to enforce propriety. This procedure is used by the default IEEE 802.11p MAC protocol which uses EDCA. Based on Fig. 1 and Table I, we see that both the CCH and SCH channels support four traffic classes each having different priorities. Therefore, allocating more time to CCH will considerably reduce the delay of critical message since medium access is faster.

In the application proposed in this paper, a more centralized QoS differentiation is required. The centralization is enforced by the AP based on evaluation of the remaining charges in all of the EVs and based on the information fed back form the smart grid at that moment. It is essential to highlight that a distributed QoS mechanisms used by the IEEE 802.11p MAC allow different STAs to use contention based on internal decisions of remaining battery charge levels and hence making independent priority levels. Therefore, if multiple EVs decide that their battery levels are low, they all consider this situation as a high priority, and use the same AC leading to higher contention. In the QCEV mechanism on the other hand, since STAs send their battery levels, the AP decides which STA deserves the highest channel access priority. We show that the reduction in delay becomes more obvious when the number of STAs increase due the reduction in the contention level.

Fig. 4 shows the throughput when the IEEE 802.11p and the QCEV are used. We show that the throughput is always higher when the QCEV mechanism is used, this is due to the reduction in the contention when centralized QoS mechanism is used.

### Algorithm 1 QCEV Algorithm at the AP.

//Network establishment phase
//For all STAs
AP ← (SoC, (d) & (D))
//For N STAs find Min (SoC) & Max (d)
STAMin\((SoC),Max(d)\) ← xSTA
AP ← ((CC), (DC) & (TC) from SGS
//Find Min (CC) & Min (TC) for xSTA
AP broadcast xSTA\(A_{P-d_{xSTA}}\), xSTACCMi.xSTA & xSTA_TCM
//Find Min (CC) & Min (TC) for \([N-I]\) STA
Transmit Min \([CC_{(N-1)}]\) & \([TC_{(N-1)}]\)

(EDCA Algorithm)

### VI. SIMULATION RESULTS AND ANALYSIS

To evaluate the performance of the QCEV scheme, we use QualNet [23] network simulator to simulate the scenario described in Fig. 2. We assume that there are \((N)\) EVs on the road at a given time and that these EVs travel at an average speed of 60 km/h. We run each simulation for 1 hour and average 10 simulation runs to obtain the results.

Fig. 3 shows the end-to-end delay from the xSTA to the AP. We show that when the default QoS defined in the IEEE 802.11p MAC protocol is used, the end-to-end delay is always higher compared to the situation where the QCEV is used. This reduction in delay takes place since the distributed QoS mechanisms used by the IEEE 802.11p MAC allow different STAs to use contention based on internal decisions of remaining battery charge levels and hence making independent priority levels. Therefore, if multiple EVs decide that their battery levels are low, they all consider this situation as a high priority, and use the same AC leading to higher contention. In the QCEV mechanism on the other hand, since STAs send their battery levels, the AP decides which STA deserves the highest channel access priority. We show that the reduction in delay becomes more obvious when the number of STAs increase due the reduction in the contention level.

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### VII. CONCLUSIONS

Reliable and real-time communication between EVs/PHEVs on one side and the smart grid on the other side has been identified as one of the main challenging issues to successfully integrate these two technologies. In fact electrical utility operators have set up specific delay and reliability requirements for certain applications. In this paper we presented a QoS scheme for charging Electric Vehicles (EVs) (QCEV) in a...
smart grid environment. Our scheme considers the charging requirements of EVs communicating with the Access Point (AP) using the IEEE 802.11p protocol and centrally provides Quality of Service (QoS) differentiation to EVs that require immediate access to a charging infrastructure. The QCEV scheme controls the channel access of contending EVs by forcing EVs with less priority to use lower Access Categories (ACs) with longer channel access mechanism. Our simulation results show that QCEV could effectively reduce the end-to-end delay and increase the throughput for EVs with high priority. Furthermore, simulation results show that as the number of EVs communicating to an AP increase, the effectiveness of the QCEV scheme becomes more pronounced.

As a future work we intend to investigate the performance of the QCEV scheme in multihop environment where the data packets are routed through multiple EVs before reaching the AP.

REFERENCES