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An Efficient Scheduling Scheme on Charging Stations for Smart Transportation*

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Abstract. This paper proposes a reservation-based scheduling scheme for the charging station to decide the service order of multiple requests, aiming at improving the satisfiability of electric vehicles. The proposed scheme makes it possible for a customer to reduce the charge cost and waiting time, while a station can extend the number of clients it can serve. A linear rank function is defined based on estimated arrival time, waiting time bound, and the amount of needed power, reducing the scheduling complexity. Receiving the requests from the clients, the power station decides the charge order by the rank function and then replies to the requesters with the waiting time and cost it can guarantee. Each requester can decide whether to charge at that station or try another station. This scheduler can evolve to integrate a new pricing policy and services, enriching the electric vehicle transport system.

1 Introduction

The Republic of Korea was nominated as world’s leading nation in the smart grid technology [1]. The smart grid is the next generation power network which combines information technology with the legacy power network to optimize the energy efficiency [2]. It can also make it possible to exchange information on power generation and consumption between those parties, bringing the era of prosumer, which means any individual can be both consumer and producer of energy at the same time. The Korean national government opened the smart grid complex in Jeju area, pursuing 5 goals of smart power grid, smart place, smart transportation, smart renewable energy, and smart electricity service [1]. Among these, the smart transportation part installs electric charging stations along the road network and at homes to accelerate the deployment of electric vehicles [3]. More specifically, the charge station will be installed in the existing gas

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stations and LPG filling stations, public institution buildings, shopping malls, and airports.

Electric vehicles are charged on any charging stations, but it takes quite a long time in stations. Moreover, the requirement on the charge is usually different vehicle by vehicle. For example, a vehicle arrives at the station at 2 PM, needs 5 kW with the unit price less than 1 USD, and can afford to wait until 3 PM. Thus, the charging station must schedule the service order for multiple vehicles to meet the requirement of as many vehicles as possible. In this regard, this paper is to parameterize the vehicle-side requirement on battery charging and propose a scheduling scheme which decides the charge order to improve the satisfiability of vehicles. The station charges the vehicles according to this order and informs a vehicle of the estimated service time. The vehicle can confirm its reservation, renegotiate with a modified requirement, or choose another station. This paper is organized as follows: After issuing the problem in Section 1, Section 2 describes the background of this paper. Section 3 explains the service scenario and proposes the rank function. Section 4 summarizes and concludes this paper with a brief introduction of future work.

2 Background

Smart transportation is one of the most important areas in the smart grid. Electric vehicles need nation-wide power charge infrastructure, possibly creating a new business model embracing diverse vehicles, charging stations, and corresponding services [4]. Based on the provided information such as price plan of each station and a personal schedule, a user can decide when to charge his car, while reselling the surplus back to the power company during the peak hours. In addition, the battery-charged power can be used as back-up power source [5], so we can expect the improvement in the power network efficiency and reliability as well as the reduction of greenhouse gas emissions. The charging station can be installed in diverse places as shown in Figure 1. Drivers can charge their vehicles at their homes, offices, public institutes, shopping malls, charging stations, and the like. Noticeably, while the car is being charged, the driver can work at his office or take shopping at the mall. In those places, many vehicles will be concentrated and they must be served according to a well-defined reservation strategy.

3 Scheduling Scheme

3.1 Service Scenario

To simplify the problem, this section first assumes that the station charges one vehicle at a time, however, this restriction can be easily eliminated. In our scenario, a driver tries to make a reservation at a charge station before it arrives at the station via the vehicular network, specifying its requirement details as shown in Figure 2. Each requirement consists of expected price, estimated arrival time,
tolerance bound on waiting time, minimum and maximum charge amount, and so on. Receiving the request, the scheduler calculates the rank function for the new request, reorders the request along with the existing ones, and checks whether the station can meet the requirement of the new request without violating the constraints of already admitted requests. The result is delivered back to the vehicle, and the driver can confirm the request, attempt a renegotiation, or choose another station. Here, it must be mentioned that there are several commercially available vehicular networks, for example, DSRC (Dedicated Short Range Communication) and IEEE 802.11 WLAN [6].

3.2 Rank Function

Each vehicle sends a reservation request message consist of the fields shown in Figure 3(a) via its in-vehicle telematics device and the corresponding vehicle network [7]. The scheduler processes requests one by one, namely, reorders the requests based on the rank function, estimates the service completion time, checks whether the completion time lies within the tolerance bound for all requests, and finally sends back to the requester whether the station can accept the request or not. The scheduler defines the rank function, $T_v$, as shown in Eq. (1):

$$T_v = ETA_v + WT_v + \frac{C_v}{r},$$ (1)
where $ETA_v$ denotes the estimated arrival time of vehicle $v$ and $WT_v$ denotes the tolerance bound on the waiting time, that is, how long $v$ can wait until it is served. In addition, $C_v$ is the charge amount of $v$, and $r$ is the charge speed in the station, hence, $CT_v$, or $C_v/r$ means the charging time. The rank function can be executed in $O(n)$ time complexity, where $n$ is the number of requests. It can avoid the time-consuming search space traversal that takes $O(n!)$ complexity, possibly giving the prompt reply to the vehicle so that it can renegotiate or try another station.

<table>
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<th>(a) Request specification</th>
<th>(b) Scheduling</th>
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<tr>
<td>A</td>
<td>12:00</td>
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<tr>
<td>B</td>
<td>12:00</td>
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<td>C</td>
<td>12:00</td>
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<td>E</td>
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<td>F</td>
<td>13:00</td>
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Figure 3 shows the sample scenario to describe how the proposed scheme works. The requests from $A$ to $F$ arrive at the scheduler sequentially, and each of them invokes the scheduler, respectively. Until request $C$, the service order decided by $T_v$ can charge all vehicles within their tolerance bound. However, for $D$, the service order $(C, A, D, B)$ cannot meet the tolerance bound requirement.
for $B$ and $D$. As a result, the scheduler rejects $D$. For requests $E$ and $F$, which have the later arrival time, can be served and accepted.

The proposed rank function is highly likely to admit the request having a long tolerance bound, as it can wait a relatively long time and give flexibility to the scheduler. The station prefers those requests and can possibly give a discount. In addition, the estimated arrival time can be decided by the in-vehicle navigation module by the locations of the current vehicle and the charging station. We can assume that the estimation is quite accurate. Generally, the in-vehicle computer system has sufficient computing power especially in electric vehicles, as it handles a lot of stream data to monitor and sometimes control vehicles [8]. However, if the vehicle arrives ahead of schedule, it must wait. On the contrary, if the vehicle arrives after the reserved time, its reservation is adjusted or sometimes cancelled.

4 Concluding Remarks

This paper has designed a reservation-based scheduling scheme for the charging station to decide the service order of multiple vehicles to improve the number of charging requests the station can serve. The proposed rank function takes into account the estimated arrival time, delay tolerance bound, and charging speed. The rank function decides whether a new request can be served in a linear execution time. It can also integrate additional criteria such as pricing policy, for example, which gives a discount to the request having a long tolerance bound. As future work, we are first planning to verify the efficiency of our scheme in terms of schedulability, comparing with the brute force scheme which can find the optimal solution even in unacceptable time. Next, a charging station selection algorithm is to be designed for the convenient driving of electric vehicles.

References