An Advanced Smart Management System for Electric Vehicle Recharge

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Abstract—Recent studies about climate change are mandating a drastic reduction of green house gas (GHG) emissions. Solutions include the utilization of renewable energy sources (e.g., wind, solar energy) and the increased utilization of hybrid and electric vehicles (EVs). In this scenario ICT can play a significant role by fostering the smart utilization of current energy and transportation infrastructures (smart grid and smart cities). This paper presents a new ICT infrastructure to enable the intelligent exploitation of distributed energy resources in order to minimize the EV charging times while optimizing the efficiency of the electrical infrastructure. The proposed system is based on a distributed communication infrastructure (both wired and wireless) aimed at collecting/emitting bidirectional energy dispatching opportunities for electric vehicles. The envisaged system seamlessly interconnects emerging self-organizing wireless technologies (i.e., VANETs and Wireless Mesh Networks), with legacy wired communication technologies, to guarantee a fast rollout of the EV charging service with minimum investments in communication infrastructures. The performance of the proposed solution is evaluated in terms of its sustainability by analyzing the quality of the charging service as perceived by the users, and the capability of the charging infrastructure to meet the charging requests in a timely manner.

I. INTRODUCTION

Recent studies about climate change are mandating a drastic reduction of green house gas (GHG) emissions. Solutions include the utilization of renewable energy sources (e.g., wind, solar energy) [1] and the increased utilization of hybrid and electric vehicles (EVs) for improving the sustainability of the transportation systems [2]. Several reasons can explain the momentum gained by these solutions in the last two years. On the one hand, liberalization and deregulation processes, especially in the European electricity market sector, are transforming citizens from passive consumers of electricity provided by large-scale distribution systems, to active market players and micro-producers at individual and community levels [3]. On the other hand, the release of a handful of affordable electric cars, as well as the increasing concerns for the environment, the public health, the non-sustainability of fossil fuels, are fostering the market penetration of EVs.

However, several infrastructure problems stand in the way of the widespread use of EVs. While EVs could be charged by using conventional household electrical outlets (although with significant charging delays), the development of a large-scale public charging infrastructure is far away and costly to build. Moreover, while the EV technology enables the shift from fossil fuel dependent combustion engines to electrical engines, much of the electricity used to charge the batteries will still be produced via unsustainable methods. Finally, a major concern for the utilities is the impact of the demand of electricity for charging the EVs, such as sharp increase in demand during peak hours or in sub-regions of the grid [4]. Similarly, several infrastructure problems are hindering the large scale integration of renewable energy sources into the electrical grid, such as the availability of a reliable mass storage systems [4], and information and control infrastructures for the management of the distributed generation. It is important to observe that wide-area monitoring and control functionalities of the power devices in the current power grids already exist and they are based on Supervisory Control and Data Acquisition, and Energy Management System (SCADA/EMS) [3]. However, the SCADA/EMS is centralized and, because of the unforeseen growth of the information exchanged by energy consumers and energy suppliers to optimize energy utilization, the EMS is facing scalability and reliability issues [5]. Most importantly, such smart grid technologies are envisioned only for monitoring and controlling residential energy consumers and cannot be applied to the case of mobile energy consumers such as EVs.

The vision advocated in this paper is that it is rapidly emerging the need for an advanced smart management system for electric vehicle recharge (SMS-EV) to jointly control EV charging and distributed energy resources (i.e., renewable sources). Such system is built upon an interconnected mesh of residential/commercial charging docks, or charging stations. The SMS-EV will need to: (a) ensure a balanced usage of the electrical infrastructure minimizing the impact of EVs on grid reliability and peak demands; (b) improve the sustainability of the EV charging infrastructure by optimizing the utilization of the locally generated renewable energy; and (c) increase user satisfaction on EV charging service (e.g., minimizing EV charging time). A key position of the proposed approach is that SMS-EV relies on emerging wireless networking paradigms, in particular vehicular ad hoc networks (a.k.a., VANETs [6]) and community wireless mesh networks (a.k.a., WMNs [7]), to simultaneously achieve: good coverage without dense deployments, scalability, communication reliability, and fast and incremental deployability with a low initial investment (low CAPEX) because of the small number of fixed infrastructure connections. In addition the SMS-EV provides seamless support of driver mobility and exploit also Delay Tolerant
Networking (DTN) [8] for information dissemination. Finally, the SMS-EV also features an intelligent service layer capable of providing customized information and services to drivers based on specific policies. To validate the sustainability of the proposed architecture and its potential benefits, this paper presents a preliminary set of simulation results to quantify the quality of the charging service as perceived by the users, and the capability of the charging infrastructure to meet the recharge requests in a timely manner in a broad range of system conditions.

II. BACKGROUND AND RELATED WORK

It is a common belief that introducing communication capabilities (i.e., feedback and control) in the objects involved in many human activities will help to optimize the service provisioning and to increase user satisfaction. This idea gave birth to many concepts such as the Internet of things [9], smart cities [10], Intelligent Transportation Systems (ITS) [11], smart grids [12], to name a few.

In general, the implementation of services in either the smart grid or in the ITS follows the approach of a two-layer architecture: the service stratum and the communication infrastructure or transport stratum [13], [6]. The service stratum includes different basic services (i.e., the service entities) that can be composed and interact to implement a specific application, while the network infrastructure supports the communication between client and services and between service entities.

In current smart grid systems the service stratum is centralized. For example the wide-area monitoring and control of smart grids is based on a centralized Supervisory Control and Data Acquisition, and Energy Management System (SCADA/EMS). The SCADA/EMS gathers all the data coming from distributed sensors, elaborates them, and, if needed, sends the control signals back. The transport stratum utilizes protocols such as IEC 60870-5 [14], Distributed Network Protocol (DNP3) [15], and IEC 61850 [16] and communication systems based on power line communications or on microwave technologies for interfacing with the EMS/SCADA [3]. However, such protocols are not capable of meeting the capacity requirements of the monitoring and control data to be exchanged in a distributed energy source (DER) environment.

On the ITS side, one of the means to implement ITS is to leverage vehicular networks (VANET). Recently, VANET have received great attention from both the industry and the academia, due to their potential importance in various applications ranging from road safety and intelligent transportation systems, to on-board Internet access [6]. From the service stratum perspective VANET technology comprises an application layer for enabling services, such as support of solutions for collision avoidance and provisioning of travel information to drivers. A basic message set is defined in the SAE J2735 standard [17] that can be used and/or extended for developing other applications for advanced services, e.g., dissemination of parking availability information to drivers. From the transport stratum perspective VANETs represent the application of mobile ad-hoc networks (MANET) to the vehicular world and are based on wireless network protocols. However, classical wireless networking protocols are not well suited for the high mobility that characterizes vehicular applications. Therefore, new mechanisms have been proposed for faster connection establishment, low latency handoffs, and more reliable data transfers [18], [19]. However, vehicle-to-infrastructure (V2I) communication requires huge infrastructure investments, and vehicle-to-vehicle communication is a more viable solution in the near future. For these reasons, to support communications from moving vehicles also without one-hop Internet connections, or in challenging environments under unreliable conditions and low node density, a number of projects have proposed to extend the VANET model by using Delay tolerant Networking (DTN)-based communications [8].

Finally, the literature on control strategies to optimize the energy flows between the power grid and the EV is particularly rich. Several studies address the problem of regulating the charging of electric vehicles for mitigating its negative impact on the grid [20], [21]. For instance, a peak demand is likely to occur during the weekday evening hours due to a large number of EVs starting their charging without any coordination but immediately after a vehicle arrives at home. In addition, as a result of the market dynamics, the price of electricity increases during peak hours, which can results into more expensive charging services. Recently many papers have developed new control strategies for EV charging, which try to minimize peak loads, to flatten aggregated demands [22], [23], [24], [25], to reduce frequency fluctuations [26], [27], to minimize charging and generation costs [28], [29], or consider diversified objectives simultaneously [30]. Those papers consider various cases, such as individual EVs performing independent decisions to minimize their own operating costs, centralized controllers collecting information of all EVs and optimizing over the charging profiles of all EVs, and decentralized decision processes where individual EVs takes into account the collection of charging strategies adopted by other EVs. In [31], a prediction-based charging scheme is presented to achieve low charging cost by dynamically predicting the market prices during the charging period and determining the appropriate time to charge. In [32] the problem of planning the individual charging schedules of a large group of EVs is formulated with the additional constraint of respecting grid capacity limits. Multi-agent system for the decentralized management of EV charging are also described in [33], [34]. However, only few recent papers have addressed the problem of designing scheduling schemes to mitigate the drivers’ discomfort by minimizing the waiting time for EV charging at the charging station [35], [36].

III. THE SMART MANAGEMENT SYSTEM FOR ELECTRIC VEHICLE RECHARGE (SMS/EV)

The SMS-EV is proposed for a scenario in which distributed energy resources (DERs) are provided by small energy producers (i.e., charging stations) that make their energy available for charging EVs. We envision that such small producers are set up in an unplanned fashion and they can be either components of
micro-grids, i.e., communities that can generate and store their own electricity and disconnect and reconnect from the utility power grid in instant fashion; or single residential/commercial stations, which can be in any location but, in general, they are assumed to be scattered and located in suburban and rural environments.

To guarantee fast service deployment and to reduce the initial investment, we assume that only few charging stations have a connection to a wired telecommunication infrastructure. In this case, a low-cost wireless mesh infrastructure may be in place enabling the coordination among charging stations [37]. However, especially in suburban and rural areas, charging stations might be too scattered to form a fully connected wireless mesh. In this case EVs have a dual role: not only moving EVs cooperate to distribute EV-generated information (e.g., recharge requests), but they also help guaranteeing full connectivity between charging stations far apart by disseminating infrastructural information (e.g., charging station status) through, for example, carry-store-and-forward techniques [8]. Indeed, for a timely and efficient re-charging, EVs need to be informed by the charging infrastructure about the location of the charging stations and, most importantly, to receive updates on energy availability of charging stations and expected waiting time before charging. In principle, traditional cellular technologies could be used to provide EVs with unconstrained access to the SMS-EV and to allow consistent and ubiquitous provisioning of SMS-EV services. However, the adoption of such architectural model may considerably increase the operational costs of the system, and make it difficult to provide diversified value-added services with broadband requirements. On the contrary, to support ubiquitous high-speed communications between EVs and between the EVs and the charging stations, the SMS-EV relies on emerging Wireless Access in Vehicular Environments (WAVE)-based technologies [6], a solution more cost-effective than the traditional cellular systems (e.g., Long Term Evolution — LTE). Thus, a key original trait of the envisioned SMS-EV is the transparent integration of vehicular and mesh-based wireless technologies with traditional wired telecommunication systems, enabling integrated services for both static and mobile energy customers.

From the service perspective, the SMS-EV can be considered as an evolution of today’s satellite navigation systems. An additional and original feature of the SMS-EV is service personalisation. EV drivers receive customized information based on their preferences and on system policies, which may aim at minimizing charging time, minimizing charging cost, minimizing deviation from planned route, minimizing charging station congestion, minimizing demand peaks, etc. SMS-EV services and policies are implemented in a hybrid fashion, that is, some of them are centralized/global while some others are distributed/local. The hybrid implementation has the advantage of exploiting the locality of some transactions (request-reply) to guarantee them low latency, and the global knowledge of a centralized system to provide optimality. Transactions are classified based on their latency and reliability requirements. The transactions that require a small latency between request and reply are handled locally in a distributed manner. For example, if an EV requests charging to a charging station the decision must be taken rapidly and locally if possible: only the closer charging stations are involved in the decision taking procedure without requiring global information from stations far away. On the other hand, more coordinated decisions (e.g., such as billing, route planning with reserved charging slots) are taken in a centralized manner by gathering global information from all the stations and reservation requests by the EVs.

The architectural model of the proposed SMS-EV is illustrated in Fig. 1. The implementation of the SMS-EV is based on three main physical/logical entities: the Distributor Smart Meter (DSM), the Car Smart Meter (CSM) and the Aggregator (A). DSMs and CSMS are installed in each charging station (as part of the Road Side Unit — RSU) and in each EV (as part of the On Board Unit — OBU), respectively. The aggregator is the system controller storing and elaborating the information and implementing the optimization functions. Two types of aggregators are envisioned: a local aggregator (LA) and a global aggregator (GA). In the former, the system intelligence is located at the edge of the SMS-EV architecture in order to promote scalability and locality, while the latter keeps the edge devices simpler and favours more sophisticated centralized optimizations. LAs can coincide with some DSMs.

The SMS-EV is designed along the principles of the Next Generation Network (NGN) [13]. One of the key principles of NGN architecture is fixed and mobile convergence, where service-related functions are independent of the underlying transport technologies. First, this approach facilitates the integration of multiple access technologies, and the system design due to the existence of well-defined layers, interfaces and functionalities. Second, an NGN-compatible system speeds up the provisioning of diversified/integrated services to the EVs such as content delivery services, multimedia services, remote control services, and over-the-network device management.

In line with the NGN model, each element of the SMS-EV architecture comprises service-stratum functions and transport-stratum functions. The service stratum is responsible for elaborating/aggregating information about energy availability and for elaborating the requests upon their arrival or according to pre-established time scheduling, and for fulfilling them with possible booking of energy slots for future uses. The service stratum is also responsible for matching demand and supply and for optimizing the distributed charging infrastructure. Finally the service stratum might interact with the SCADA/EMS of the current electric grid to coordinate the energy distribution infrastructure with the electrical charging infrastructure.

For service delivery the publish/subscribe paradigm is utilized. In publish/subscribe systems producers publish services, while consumers subscribe for services in which they are interested. Then, the system is responsible for delivering published services to matching subscribers [38]. This paradigm guarantees a faster availability of information than the classical client-server approach does, and it has been already utilized in service-oriented networks. Moreover, in the service stratum the
service composition/delivery is based on message exchange among elements aimed at the collection of background information of energy availability, and at the elaboration of recharge requests and production of replies. The exchanged information, message set and communication rules is implemented by using XML-based messages and a proprietary protocol [39].

On the other hand, the transport stratum comprises all the functions and protocols to manage EV access to the network, as well as the reliable and low-latency transportation of information among different elements of the architecture (e.g., DSM, CSM, LA, GA). DSM connected to the electrical grid may access the data network through the narrow-band connectivity offered by Power Line Communications (PLC) [40]. Alternatively, fixed broadband access based on either Asymmetric Digital Subscriber Lan (ADSL) or passive optical networks provide DSM with access to the data network. DSMs/LAs/GAs are connected through a TCP/IP-based optical backbone network. Wireless mesh technologies (i.e., WiFi or WiMAX) replace wired technologies to interconnect DSMs to the data network when fixed access is not economically viable. Low-cost WAVE-based technologies are utilized for enabling information exchange between DSMs and nearby CSMs, or between CSMs.

Finally the SMS-EV can easily incorporate cybersecurity features [41]. Such features are an essential part of future smart grids and of EV infrastructures. However SMS-EV cybersecurity aspects are not detailed in this paper.

IV. POLICIES FOR EV ASSIGNMENT TO CHARGING STATIONS

An important factor for the successful deployment of the SMS-EV is represented by its sustainability. Sustainability is a multi-dimensional concept, which involves environmental sustainability (i.e., the system brings benefit to the environment with respect to traditional systems), economical sustainability (i.e., the system is economically feasible considering both social and business aspects), and technical sustainability (i.e., the system is possible with the limits of current technologies or its short-term advancements). However, sustainability also implies user acceptance and usability. For example, a key aspect to lower the hurdles to EV acceptance is represented by reducing the charging delays.

Current transport stratum technologies are foreseen to be capable of supporting EV requests both in terms of capacity and delay. For instance, the communication zone covered by a DSM using WAVE technology can reach up to 1 km [42]. In addition recent studies have clearly demonstrated that the capacity of WAVE-based wireless transmissions slowly decreases with the vehicles density and a bandwidth of the order of 5 Mb/s can be easily achieved even in very dense vehicular networks [43]. Similar considerations can be made when considering the wireless mesh backbone interconnecting groups of DSMs. Indeed, there are many examples of large-scale and high-capacity community wireless mesh networks all around the world (e.g., the Athens Wireless Metropolitan Network (AWMN) with two thousand nodes) supporting advanced broadband services [37]. Moreover, wired broadband networks can guarantee performance even higher than wireless networks. Thus, the information to be exchanged for the management of EV charging requests and the monitoring of the charging infrastructure, even when aggregated within the wireless backbone, can be delivered with negligible delays. In any case the communication delays (less than a second) is order of magnitudes lower than the charging times (tens of
Based on the above considerations, the evaluation of the SMS-EV can be mainly based on quantifying its sustainability from the perspective of both the end users (i.e., EV drivers) and the service providers (i.e., electrical utility providers and micro producers of renewable energy resources). More precisely, user sustainability is intended as the capability of the SMS-EV of optimally satisfying users’ service requests by assigning charging stations and charging slots so as to minimize the charging time or to guarantee the best tradeoff between charging times, charging costs, and deviation from the planned route.

In this paper two policies are proposed and evaluated to assign EV to charging stations. Both the policies are assumed to be run by the SMS-EV aggregator. The first policy, named closest station (CS) policy, assigns the EV to the charging station closest to the position occupied by the EV when it requests charging. The second policy, named min waiting time (MWT) policy is based on assigning the EV to the charging station, within the EV reachability, that, upon charging request, guarantees the lowest charging delay. The foreseen charging delay for the EV is computed as the sum of the time to complete the charging of the EVs currently present at the charging station and the charging time of the EV performing the request. If a fueling slot, in a station, is free the foreseen charging delay will correspond to the EV charging time only. If two stations have the same charging delay, the traveled distance is minimized and the nearest station among them is chosen.

V. System Evaluation

A. Simulation Setup

To evaluate the sustainability and performance of the proposed SMS-EV system a full-fledged simulator is under development. The simulator comprises three inter-dependent components. The first component generates EV mobility traces according to realistic vehicular mobility models implemented in open-source traffic simulators, such as VanetMobiSim [44]. These mobility traces are provided as input to the other modules of the simulators. The second component generates the EV service requests based on well established models of the typical EV load and charging profiles, such as the ones specified in [45]. It is important to note that the average duration of the charging depends on the distance travelled, which depends on the mobility traces. Finally, the third component implements the system intelligence. This module simulates how service requests are forwarded to the aggregators to be elaborated either locally or globally based on the requested service characteristics. More precisely, this model describes the communication technologies and protocols implemented at the EV to be capable of estimating the delay necessary to forward the EV service requests to the aggregators. To this end, such model receives in input EV mobility traces from the first simulator component and EV service requests from the second module. Finally, this module contains the various optimization policies that are used to maximize system sustainability.

To analyze the impact of different vehicle densities and trip distances on the system performance, in the following simulations the EVs move within a square area of variable size, ranging from 4 km, which is representative of a typical urban scenario, to 50 km, which is representative of suburban scenarios. The simulation area is subdivided into four non-overlapping squared sub-areas and a charging station is located at the center of each sub-area. Given that the number of charging stations is kept constant, the larger is the simulation area the longer, on average, is the distance that an EV should travel before reaching the target charging station. It is also important to notice that the results shown in this study have been obtained using a simplified version of the above described simulator and a client-server paradigm, that does not impact the obtained results. More precisely, EV charging requests are generated following a Poisson process with an average inter-arrival rate \( \lambda \). In addition, new EVs are uniformly located within a sub-area. However, to simulate unbalanced conditions
EVs are more densely concentrated in one of the four sub-areas. In particular, the probability for an EV to be within the densest sub-area is two times higher than the probability of being in the other three areas. EVs move within the network at an average speed of 50 km/h (which is maximum speed allowed within an urban area). Differently from [46], in the considered scenario, the route followed by the EVs to reach their destination is not preplanned (thus deviations from the route are allowed) and the recharge must follow closely the charging request both in time and space. Without loss of generality EVs move along the shortest route (i.e., the straight line connecting two points) to reach the charging station. The recharge time is uniformly distributed in the interval [2 min, 30 min]. Finally, to quantify the system performance we measure the average EV waiting time, which is defined as the average period of time between the time an EV arrives to the selected station and the time it starts recharging its batteries. This delay is composed of various components. One is the time needed to the message carrying the service request reach the aggregator, and it depends on network topology and communication technologies. Then, there is the EV charging time. Finally, there is the time the EV spends at the charging station waiting for the other EVs, arrived earlier, to complete their charging procedures. In principle, another component is the time needed by the aggregator to elaborate the service request and formulate the reply but, in the following simulations, it is assumed to be negligible.

B. Homogeneous scenarios with 3G/4G communication technologies.

In this section we present a set of simulation results obtained by assuming that all the EVs are equipped with cellular (3G/4G) communication technologies. In this case, the EV service requests are directly sent to the DSM using the cellular network. This will clearly minimize the communication delays. On the downside, a communication fee must be paid by the users to access the communication services.

Fig. 4 plots the average waiting time experienced by the EV in a 4 km x 4 km area as a function of the interarrival rate of the vehicles in the system (which corresponds to the interarrival rate of the charging requests) for the two considered schemes described in Section IV. The shown results confirm that the average waiting time increases with the increased density (i.e., increased interarrival rate) of EVs in the network. Moreover, the MWT policy largely outperforms the CS strategy. This is mainly because, in the considered scenario, EVs might need to wait more to start the charging if they always go to the closest station that may be already serving other EVs than going to a farther but empty or less loaded charging stations. Fig. 5 shows the results obtained in a 40 km x 40 km area. In this case, when the CS policy is used, the delay experienced by EVs is slightly less than the one in the 4 km x 4 km area scenario. On the contrary, when the MWT strategy is used the delay experienced by EVs is slightly higher than in the 4 km x 4 km area scenario. These counter-intuitive results can be explained by noting that within a small area (i.e., 4 km x 4 km) the time spent to reach the farthest station is small compared to the time needed to charge the EV battery. On the other hand, in a very large area (i.e., 40 km x 40 km) the time needed to reach a farther, although less crowded, station may be significant and it almost nullifies the benefit of avoiding closest but already full stations. In addition, if the travel time to reach the target station is large (as in suburban scenarios), there might be many EVs that have selected the same station but are not yet arrived. Since we assume that EVs make their decision without knowing other EVs’ decisions there is a non negligible probability that the decision is made with an outdated information of the status of the charging station. In other words, the number of EVs waiting at a charging station at the time of a new EV service request may be significantly different from the number of EVs that are at the charging station when the EV that made the service request arrives.

The same trend is confirmed by the results reported in Fig. 6,
which are obtained by keeping constant and equal to 1.5 ms the interarrival time between EV charging requests but varying the size of the considered area. The EVs’ speed is 50 km per hour independently of the area size. The figure shows that the average delay experienced by the EVs decreases when increasing the area size if the CS policy is utilized, while it increases if the MWT policy is used. Such behavior can be easily explained through the considerations elaborated for explaining the differences between the results shown in Fig. 4 and Fig. 5. It is also useful to note that there is a critical area size (50 km X 50 km in our settings) where the two policies provide very similar delay performance.

C. Heterogeneous scenarios with mixed 3G/4G and 802.11-based communication technologies.

In this section we present a set of simulation results obtained by assuming that only a fraction of the traveling EVs are equipped with cellular transceivers, namely cellular EVs, while all the other EVs have only 802.11-based radio interfaces. This second class on EV cannot directly communicate with the aggregators, but they need the help of nearby EVs to forward their service requests to the closest cellular EV. Each additional wireless hop crossed by a service request increases the total transmission delay. For simplicity, in the simulations, each additional wireless hop is assumed to add one second to the total time needed to an EV service request to reach the closest cellular EV. Each additional wireless hop is assumed to add one second to the total time needed to an EV service request to reach the closest cellular EV. In addition, since the EVs arrive in the simulation area in a random manner, it might be possible that at the time a new service request is generated there are not cellular EVs, especially if the percentage of cellular EVs over non-cellular EVs is low. In this case the service request is rescheduled after 5 seconds.

Fig. 7 plots the average waiting time experienced by the EV in a 4 km x 4 km area as a function of the percentage of cellular EVs in the system on average for the two considered schemes described in Section IV and for an interarrival time between EV requests equal to 1.5 ms. Fig. 8 shows the results obtained in a 40 km x 40 km area. When the percentage of cellular EVs is close to 100%, the obtained delays are very similar to the ones shown in Fig. 6 for the same area sizes. However, when this percentage decreases the overall EV waiting time necessarily increases because transmission delays also increase. It is useful to notice that for very low percentages of cellular EVs (below 30%) EV waiting times have a steep increase due to the fact that many EV service requests need to be rescheduled.

VI. CONCLUSIONS

This paper presented an advanced smart management system for electric vehicle recharge. The system represents an effective way for fostering the development of EVs and exploiting distributed energy resources. Two charging stations assignment policies have been evaluated: one that assigns the EV to the station closest to the position where the request is made, namely the CS policy, and another one that assign the EV to the station that minimizes its average service time, name the MWT policy. While the MWT policy largely outperforms,
in terms of average service delay experienced by EVs, the CS policy if an urban environment is considered, the two policy performance are almost equivalent when a suburban environment is considered.

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