# Proxy Mobile IPv6 for Electric Vehicle Charging Service: Use Cases and Analysis

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***Abstract*—It is widely acknowledged that the key limitation to a raising market deployment of Electric Vehicles (EV) is correlated to the anxiety related to electric vehicle charging services (EVCS). From a user perspective, the electricity service should provide widely available and easily reachable charging stations with transparent payment options. From electricity operator perspective, charging vehicles should be well scheduled in time and space to avoid sudden burst of requests. Such EVCS should be conducted before reaching a charging station as well as ubiquitous and transparent to the mobility of EVs. An efficient heterogeneous communication system is then required. The centralized nature of the EVCS makes a network-based IP mobility such as PMIPv6 a good choice, first to make heterogeneous technologies transparent to the EVCS, but also hides the mobility of the EVs to the service. In this paper, we first present the mapping between the charging type and use cases of the EVCS. We then describe the required extensions to PMIPv6 to be integrated to the EVCS, and finally via a near-to-real testbed show that the EVCS satisfies the data delivery time required by the IEEE 1646.***

***Keywords*—*Electric Vehicle, Electric Vehicle Charging Service, Proxy Mobile IPv6, Mobility, Testbed.***

## I. Introduction

The number of vehicles in use is set to increase exponentially in recent years (1.015 billion in 2010 [1]). This trend causes some serious issues regarding energy sources like increasing in fuel demand and costs [2] as well as environmental concerns [3] and air quality. On one hand, it encourages the production and use of clean and efficient energy vehicles in which the electric vehicles (including full electric and plug-in hybrid electric vehicles, in common, EVs) belong to. On the other hand, the evolution of battery technology allows increasing the battery capacity while decreasing the weight/size of battery pack and reducing the costs. This context makes the EV a promising choice particularly for individual mobility in the cities.

In order to gain the customer acceptance of the EV, the charging infrastructure needs to be deployed at least as numerous and widespread as the fueling stations. Yet, unlike the fueling station, the various available charging strategies requires unprecedented interactions between drivers and the Grid operators. Second, the type of charging stations will range from commercial stations to single plugs operated in parking lots or in residential areas. Altogether, this will lead to a segmentation of Electric Vehicle Charging Services (EVCS), with a complex tracing of charging contexts and payment, which would make the charging process difficult and charging capacity/need unforecastable for Grid operators, adding anxiety to users and Grid operators. One solution to mitigate such situation is to make heterogeneous charging strategies and stations, as well as and the natural mobility of EVs transparent to the EVCS.

As stated in [4], the critical requirement to get energical and economical benefits from Smart-grid and EVs is to reach an optimal scheduling of charging EVs and storing electricity by EV. Uncoordinated burst of EV charging may cause a huge energy demand that can result in the electrical grid congestion, while storing electricity by EVs may be inefficient if required immediately elsewhere. Thus, it is important for Grid operators to monitor the necessary data (like energy consumption and demand) and to assign and route vehicles to the appropriate charging stations supporting their required charging policies. Such negotiation cannot be conducted at the charging station but must be conducted while driving. The EV therefore needs to communicate with the charging infrastructure [5]. In this context, several access technologies (e.g., WLAN, LTE and Power Line Communication (PLC) [6] [7]) must be used at different phases of the EVCS, such as LTE while driving, WLAN while approaching a charging station, and PLC while being docked at a charging station. Such heterogeneous communication technologies should be transparent to the user, the Grid operator and to the EVCS in order to maintain the service context.

Although there are a lot of publications about the electric vehicle charging system, a limited work considers it as a service. Authors in [8] outline a set of service elements of a charging service provider: energy services, incidental services and add-on services. Authors in [9] and [10] briefly introduce some access technologies (such as PLC, WLAN, and GSM) to gather data from the EV and the Grid for control purpose. Particularly, there were no publications proposing an effective way to manage a large number of EVs regarding their availability, capability and location which are the crucial factors for the EV integration into Smart-grid.

In this paper, we propose an EVCS solution from both user and Grid operator point of view. For the user, it provides an ubiquitous and transparent charging service at different scenar-

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ios (at home, at a charging station and at a parking), making charging an EV as simple as possible. It also helps the Grid operator to efficiently manage the user consumption/demand to control the load on the grid especially when a large number of EVs is considered. From the centralized nature of Smart-grid services, a network-based IP mobility management solution, Proxy Mobile IPv6 (PMIPv6) [11], is most appropriate to federate segmented charging services and make the charging experience transparent to EVs mobility as well as the communication technology used by each phase of the EVCS. By using PMIPv6, the service takes care of the EV mobility, handling vertical and horizontal handovers between different communication technologies. Yet, IPv6 address preservation in PMIPv6 remains an issue in such context, and we provided a solution by relying on a logical interface approach to hide the change of interface to the IPv6 stack.

We will first present the charging system deployment in the context described in this paper, and the typical use cases for EVCS. We then introduce the various phases of the EVCS with the corresponding communication technology to use. Next, we will describe our extensions to PMIPv6 to be integrated and used by an EVCS. Finally, we will validate the EVCS concept and the performance of PMIPv6 for the EVCS against benchmark from IEEE 1646. A near-to-real testbed which is a combination of real and virtual machines has been deployed to reduce the hardware cost and to provide more flexible experiment. A real PLC connection provided by partners from the VELCRI project is used to obtain realistic results.

The structure of the paper is as follows. Section II describes a solution for EVCS regarding different charging use cases, design principles, and operations. Section III briefly introduces PMIPv6 in the context of EVCS. Section IV describes the testbed and experiment scenarios while Section V presents the experiment results and discussions. Finally, conclusions and perspectives are presented in the last section.

## II. Solution for Electric Vehicle Charging Service

In this section, starting from the deployment scenarios for EVCS, the usage scenarios, the design principles as well as the operations of the EVCS are provided. This section also makes an early highlight on the reasons why PMIPv6 is a good choice in the context of EVCS.

### A. Electric Vehicle Charging Deployment

In the context of VELCRI project, three types of charge have been developed, namely standard, rapid and ultra-rapid. The standard charge may take from 4 to 8 hours to provide a full charge upon the initial state of battery, while the rapid and the ultra-rapid charge need about 30 minutes and 5 minutes, respectively. The location of the charging pods may be varied, however, three typical places with the corresponding characteristics are considered:

- Charge at home: long charging time at low power;
- Charge at a station: short charging time related to average fueling time; requires a high peak power level, which limits the simultaneously charging pods at stations;
- Charge at a parking: charging time related to the time spent in the parking, reduced peak power but large amount of charging pods, which requires flexible charge scheduling.

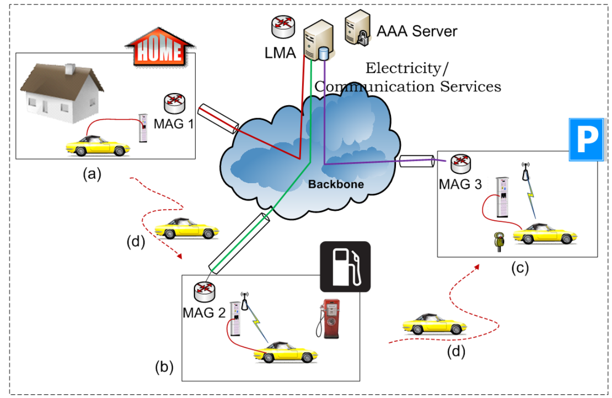

Fig. 1: General use cases of EVCS.

From the characteristics of different types of charge and locations, Table. I shows the possible deployment scenarios of charging system. It is worth noting that the scenarios marked *possible* are not considered in this paper.

TABLE I: Charging System Deployment: Type and Location

| Charge Type \ Location | Home | Station | Parking |
|---|---|---|---|
| **Standard charge** | √ | - | (possible) |
| **Rapid charge** | - | (possible) | √ |
| **Ultra-rapid charge** | - | √ | (possible) |

### B. General Use Cases for Electric Vehicle Charging Service

Based on the charging deployment scenario, this paper considers four general use cases for the EVCS (see Fig. 1): (a) - charging at home, (b) - charging at a station, (c) - charging at a parking, and (d) - moving between the parkings.

*1) Charging at Home:* The network at home can be considered as home network of the EV. The EV is typically charged in the evening (period of high energy demands and high cost) when the EV owners returns home. Thus, the EV needs to be charged intelligently. It can be done thanks to the intelligent charging management which is responsible for the automatic charge/discharge of the EV in order to lower cost and effectively control/optimize the load on the grid.

*2) Charging at a Station:* The EV, at first, communicates with the infrastructures via the wireless access technologies e.g., WLAN and LTE to assign and route vehicles to the appropriate stations. At the station, the EV will be plugged into the electrical outlet (using PLC connection) to charge. A vertical handover between WLAN/LTE and PLC will be performed that allows the EV to continue communicating with the charging station. Again, the charging process will be taken care by the intelligent charging management. The EV can also use additional services during the charging process. After finishing the charging process, the EV may receive a bill including the charging-related information (time and cost), the EV profile and operator's information.

*3) Charging at a Parking:* The steps prior to parking are similar to those in the previous case (charging at a station). The charging schedule can also be negotiated. Because of the difference between station and parking, localized service can be provided to route vehicles to the appropriate charger.

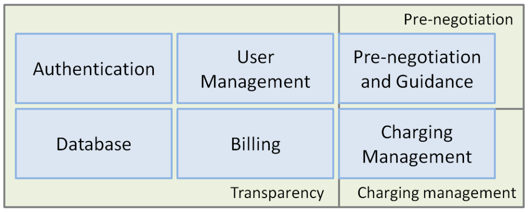


Fig. 2: EVCS modules reflect the design principles.

*4) Moving between the Parkings:* In some cases, the charging process is interrupted. The context related to this EV will be stored at a database. After connecting to another parking, the EV can make an attempt to keep the same negotiation or fall back to a renegotiation in case the parking fails to support the requirements. In the first case, the context will be restored (preservation of the context) at the current parking.

### C. Design Principles

In order to deal with different usage scenarios of EVCS, we proposed a solution guided by a set of design principles:

- Transparency: transparent mobility of the user to the service. It allows EVs to use the charging system as similar as at home (e.g, context preservation and under only one contract);
- Pre-negotiation: negotiation with the charging infrastructure before deciding to go to a specific station/parking to charge (pre-negotiation);
- (Intelligent) Charging management: cost minimizing (for user) while maximizing system reliability and stability (for Grid operator);

Besides, the EVCS should provide an easy-to-use service and secured transactions (from user perspective), as well as an effective way to manage the user information (energy demand, consumption, and location) to better control the load on the grid (from Grid operator perspective).

Therefore, the charging service can be divided into the basic modules which are mapped to the design principles as described in Fig. 2.

### D. EVCS: Operations and Functionalities

Following its design principles, the EVCS is proposed with the main operations as follows:

*1) Session initiation (via WLAN/LTE/PLC):* It is executed when an EV is connected to the charging infrastructure for authenticating/authorizing and obtaining the EV profile (context establishment). PLC is used for session initiation only in case of charging at home.

*2) Session negotiation and guidance (via WLAN/LTE):* This operation allows the EV to negotiate with one or multiple charging infrastructures to find the most appropriate one based on such metrics as charging time, cost (for user), charging type, required capacity and slots availability (for Grid operator). It is noted that this step is executed before reaching a charging station/parking thanks to the wireless access technology (WLAN/LTE). Also, additional information of the station/parking can be provided like discounts, bonuses.

*3) Charging management (via PLC):* Charging process does not start as soon as the EV is plugged, but is rather scheduled according to the capacity of the grid and the demand of the user established during the negotiation phase. Accordingly, an intelligent charging management unit coordinates the charging process on bi-directional communication link between the infrastructure and the EV while being plugged. In other words, the EV can be charged when the demand is low (G2V), otherwise it can be considered as a distributed energy source when the demand is high (V2G).

*4) Session termination (Billing, via WLAN/LTE/PLC):* When a session is terminated, electricity used or sold as well as related statistics (price, charging time and charging type, etc.) will be logged to the service provider and the charging price charged on the user account as if the user was at home.

## III. PMIPv6 for Electric Vehicle Charging Service

### A. Why Proxy Mobile IPv6?

In the context of EVCS, since an EV can be charged at different places as similar as at home, PMIPv6 is a good choice. It is because it makes heterogeneous communication technologies transparent to the EVCS and hides the mobility of the EVs to the service.

PMIPv6 - a network-based mobility management enables IP mobility for moving nodes (MNs, in this case are EV) without their involvement. This is achieved by introducing the network entity called the Mobile Access Gateway (MAG) that performs the mobility-related signaling on behalf of the MNs. In PMIPv6, the Local Mobility Anchor (LMA) is responsible for tracking the location of the MN and redirecting the MN's traffic towards its current topological location. Compared to the Mobile IPv6 [12], PMIPv6 brings some benefits such as: (i) avoiding the complexity of the protocol stack in the MN; (ii) supporting mobility without the MN's involvement; and (iii) reducing tunneling overhead and decreasing handover latency.

As we can see in Fig. 1, using PMIPv6 offers some benefits in the context of EVCS: (1) Network-based mobility management and Address preservation: The MAG where the EV is currently connected simulates the EV's home network. Therefore, the EV uses the same IPv6 address when moving in a PMIPv6 domain. So, the EV is not aware of the mobility; (2) Context preservation: This feature facilitates the charging process of the EV in case of mobility; (3) Location management; (4) Easy-to-integrate with Authentication, Authorization and Accounting (AAA) mechanism; and (5) EV-Grid interaction: The PMIP messages can be extended for collecting the EV-related information. Thanks to the advantages of PMIPv6, the energy and utility providers can provide an easy way but flexible to access their services.

### B. Typical Proxy Mobile IPv6 Operations

The operations of PMIPv6 protocol are briefly introduced as follows. When an MN is attached to a MAG in its home link (see Fig. 3), the authentication/authorization process is executed to allow MAG obtaining the MN profile from the AAA server. The Proxy Binding Update (PBU) and Proxy Binding Acknowledgment (PBA) are exchanged between MAG and LMA to allocate a Home Network Prefix (HNP) and update the current location of the MN. A bi-directional tunnel is then established between the MAG and the LMA for redirecting the traffic from/to the MN. After that the MAG sends a (unicast)

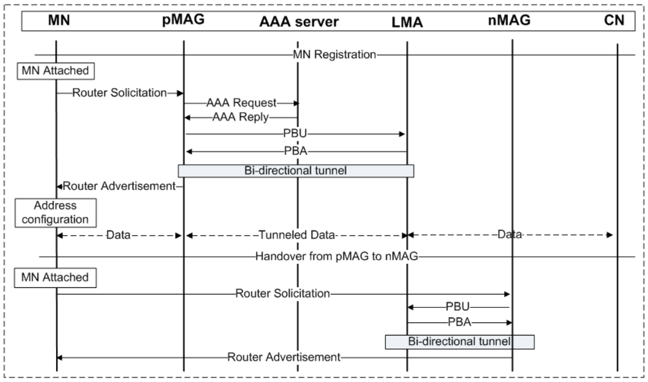


Fig. 3: PMIPv6 registration signaling.

Router Advertisement (RA) including the HNP to the MN. The MN, based on the HNP allocated, configures its address and can use it to communicate with a corresponding node (CN).

When an MN performs handover from the previous MAG (pMAG) to the new one (nMAG), the same process as above-explained is executed to update the MN's current location at the LMA. The nMAG obtains the same HNP for this MN and can emulate the MN's home network (sending RA messages with the same HNP). As a result, the MN is not aware of the mobility and continues to use the same IP address as before.

### C. PMIPv6 for Electric Vehicle Charging Service

As described in Section III.A, PMIPv6 can bring benefits to the EVCS. However, it has a few limitations. Thus, improvements are needed to make PMIPv6 suitable for the EVCS.

*1) Handover across heterogeneous access technologies (WLAN, PLC) - IPv6 Address Preservation:* Considering handover across different access technologies (vertical handover), there are several mechanisms which allow the EV obtains the same IPv6 address after handover. The first one is based on the auto-configuration mechanism by using a common identification for both PLC and WLAN interface (like Network Access Identifier). The second one uses DHCP mechanism in which two interfaces must be set with the same client identifier. However, the main limitation of two first approaches is that two interfaces cannot be active at the same time.

The third mechanism uses the logical interface technique [13] which allows to hide the different access technologies (e.g., using Linux bridge mechanism). Thus, the changing of interface is transparent to the IP stack. Moreover, two interfaces can be active at the same time. For this reason, this mechanism is more suitable than the others to facilitate the vertical handover in terms of handover latency.

*2) Context Preservation:* To support the context preservation characteristic, the MN's context need to be stored in a database/policy profile. One possible solution is that the AAA server is extended to store this type of information.

## IV. Testbed Implementation and Scenarios Description

In order to validate the proposed solution, a near-to-real testbed has been deployed. In this section, the testbed as well as the experiment scenarios are presented.

### A. Description of the Testbed

The testbed, as indicated in Fig. 4(a), is composed of one LMA, two MAGs, one CN and one MN playing the role of an EV. It is noted that the CN represents an entity in the Smart grid. The testbed is based on the User-mode Linux (UML) to create the virtual machines. The LMA, one MAG (MAG2) and the CN are the virtual machines (UML) running on a host machine which plays the role of another MAG (MAG1). Another real machine is used as an EV that connects with the MAG via a WLAN or a PLC connection. To connect the virtual machines, the virtual Ethernet connection is simulated by using a combination of Linux bridge and TAP interface. In case of PLC connection, two PLC modems are connected via coaxial cable and to the MN and to the MAG respectively. Thanks to VELCRI project, a real PLC connection is used in the testbed. The open source PMIPv6 implementation, named OAI PMIP [14], is deployed to provide PMIPv6 functionality. The actual image of the testbed is described in Fig. 4(b).

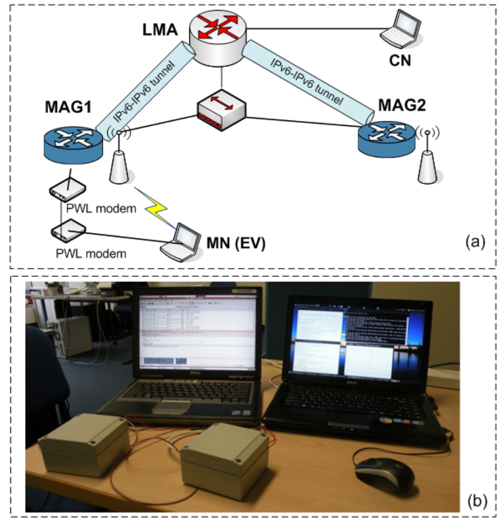


Fig. 4: Testbed: a) architecture; b) actual image.

During the experiments, a network analyzer tool (e.g., Wireshark) is used to capture the packets exchanged between the entities while a network testing tool (like Iperf) to measure the throughput of WLAN/PLC connection. The Ping application plays the role of a simple service running on EV and CN.

### B. Experiment Scenarios

In this subsection, three experiment scenarios are introduced based on the use cases given in the previous section.

- Scenario 1: Authentication and context establishment. This scenario aims at demonstrating that PMIPv6 can work correctly with PLC/WLAN.
- Scenario 2: Vertical handover between WLAN and PLC at one MAG. This scenario describes the transition between the negotiation, the charging management and the termination step.
- Scenario 3: (Horizontal) Handover/roaming between two MAGs. From the EVCS point of view, this scenario represents the mobility of the EV between the parkings. It is noted that the horizontal handover in some cases can be replaced by successive vertical/horizontal handovers. Without loss of generality, only horizontal handover using PLC is considered.

## V. Experiment Results and Discussions

At this step, the experiment focuses on the validation of the concept of EVCS and the performance of PMIPv6 (with heterogeneous communication technologies e.g., PLC and WLAN) for the future EVCS. Thus, two evaluation metrics are concentrated, i.e., PMIP functionality and performance which are translated into the corresponding EVCS metrics. The first metric aims at validating the functionality of the EVCS regarding the authentication, the context establishment, the address preservation and the service continuity in case of handover. The second metric takes into account the response time (Round-Trip Time (RTT) between the EV and the CN), handover latency, throughput and packet loss. From the service point of view, the response time is the time needed for exchanging information between EV and charging infrastructure (stations and Smart-grid) for controlling and monitoring purpose. Handover latency is translated to the time needed to acquisition of the context (IPv6 address) when switching between the operations (negotiation/charging management/termination) in the scenario 2 and when performing handover/roaming between stations in the scenario 3.

### A. Functionality Metric

When the EV was connected to a MAG via the PLC connection, the regular PMIPv6 procedures were executed (performing AAA procedures, exchanging PBU/PBA messages, updating binding state at LMA/MAG) to allocate a HNP (2001:100:7777::/64) to the EV. Based on this HNP, the EV configured its IPv6 address (2001:100:7777:021f:3cff:fe59:95a4/64) and used this address to communicate with the CN (scenario 1).

When the EV performed a vertical as well as a horizontal handover, the EV got the same prefix and kept using the same IPv6 address. By analyzing the packet exchanged between the entities, we can observer that after handover, the EV/CN continues to receive the Echo Request/Reply messages from the CN/EV. From the service point of view, that means the service continues to run after handover.

### B. Performance Metric

The average RTT between the EV and the CN via WLAN connection is 1.98ms (standard deviation = 1.47) while via PLC is 3.34ms (standard deviation = 0.47). Thus, the values satisfy the timing requirement for monitoring and control information by IEEE 1646 (16ms) [15]. We can see that although the average RTT in case of WLAN is smaller than that of PLC, the standard deviation in case of WLAN is much higher than the case of PLC. That means the PLC, as a wired link, can provide more reliable connection than the WLAN. Concerning the throughput, it is about 4.6Mpbs by using PLC. This value is adequate for the normal traffic services.

Regarding handover latency in the scenario 2, since the PLC and WLAN interfaces are activated at the same time, the handover delay is as similar to the time needed to update the EV location (between the RS and RA message). This value in the experiment is 30ms for the handover from PLC to WLAN and 42ms for the handover from WLAN to PLC. In this case, there is no packet loss. In the scenario 3, handover latency is about 2590ms. This value is much greater than that in the scenario 2. It is because the interval between the moment when the EV is detached from the previous MAG and the moment when the EV is attached to the new one is large (2283ms).

Based on the handover latency, a threshold value can be defined (e.g., 500 ms) to help the system has an appropriate behavior. For instance, if the handover latency is less than the threshold value, it can be considered as a vertical handover between two interfaces at the same MAG (scenario 2). Vice versa, it can be considered as a handover between MAGs. In the latter case, the session information needs to be stored into the profile server. Yet, some experiments are required to select the most appropriate threshold value.

## VI. Conclusions and Perspectives

This paper proposed a solution for EVCS taking into account different use case scenarios. A centralized IP mobility management solution, PMIPv6, is used to deal with the natural mobility characteristics of the EV. PMIPv6 can facilitate the usage of charging service by keeping the mobility transparent to the user and the Grid operator. Moreover, from a Grid operator point of view PMIPv6 helps to effectively manage a huge number of the EV as well as to collect the required information of the EV for the V2G and G2V purpose.

A testbed has been deployed based on the virtual mechanism that allows achieving the near-to-real results with low cost. In addition, a real PLC connection is used in the experiment to obtain the realistic results. To the best of our knowledge, this paper is the first attempt to consider PLC with PMIPv6. At this step, the experiment results validated the solution in terms of functionality as well as performance.

As future work, the EVCS modules will be developed. The (complete) service then will be evaluated in terms of its operations, functionalities and performance with different use case scenarios.

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