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Proxy Mobile IPv6 for Electric Vehicle Charging Service: Use case 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 (Grid) 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. In this paper, we introduce an EVCS for heterogeneous communication technologies, describe its requirements and the various steps of the service. The centralized nature of the EVCS makes a network-based IP mobility such as PMIPv6 a good choice, first to make heterogeneous communication technologies transparent to the EVCS, but also hides the mobility of the EVs to the service. We then describe the required extensions to PMIPv6 to be integrated to the EVCS, and finally validate our EVCS on a near-to-real testbed on an IPv6 networks over heterogeneous communication technologies (PLC and WLAN).

Index Terms

Electric Vehicle, Electric Vehicle Charging Service, Power Line Communication, Proxy Mobile IPv6, Handover, Mobility, Testbed.

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1 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 (the transportation sector is responsible for 70% of oil consumption in the US [2]) as well as environmental concerns (global CO_2 emissions from transport have grown by 44% from 1990 to 2008 [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. In addition, the price of an EV also decreases to become almost the same as a normal vehicle [4]. This context makes the EV[1] 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 gasoline service stations. But the type of charging stations will range from commercial stations to single plugs operated in office parking lots or in residential areas. 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 stations and the natural mobility of EVs transparent to the EVCS.

The only way to benefit 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 and capture 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 (charging station and Smart Grid) [5] [6]. In this context, several access technologies (e.g., WLAN, LTE and PLC) must be used at different phases of the EVCS, such as LTE while driving, WLAN while approaching a charging station, and Power Line Communication (PLC) [7] [8], 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.

In this paper, an electric vehicle charging service (EVCS) solution is proposed from both user and provider point of view. For the users, it provides an ubiquitous

[1]This paper mainly concentrates on the electric cars when mentioning about the EV in general.

and transparent charging service at different scenarios (at home, at work or at a charging station), 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) [9], 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 charging station and each phase of the EVCS. By using PMIPv6, the service takes care of the EV mobility (at IP level), 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 in this paper by relying on a logical interface approach to hide the change of interface to the IPv6 stack.

It is noted that this paper does not intend to focus on the technical aspects of PLC (that already were discussed in several papers such as [10] [11]) as well as charging issues (e.g. safety,), but introduces a charging service model regarding different use cases of PLC with electric vehicle instead.

The structure of our paper is as follows. Section 2 describes related work on the charging infrastructure, the smart grid and the electric vehicle charging service (EVCS). Section 3 proposes the EVCS model regarding its characteristics, operations, functionality as well as different use cases of the solution. Section 4 introduce the PMIPv6 in the context of EVCS. Section 5 describes the testbed and experiment scenarios while Section 6 presents the experiment results and discussions. Finally, conclusions and perspectives are presented in the last section.

2 Background and Motivation

2.1 Electric Vehicle Charging Systems

2.1.1 Charging infrastructure

Charging infrastructure plays a very important role in the EV industry. The charging infrastructure facilitates the consumers to buy/use an EV, and makes the EV more convenient. In general, there are 3 types of charging point (charger) [12]:

- Standard Charge (Level 1 charging): This type of charging point may take from 4 to 8 hours to provide a full charge (100%) depending on the initial state of battery (lowest cost).
- Fast Charge (Level 2 charging) needs a half of time of standard charge to get full level of energy (higher cost).
- Rapid Charge (Level 3 charging) needs only less than 30 minutes to get full level of energy (highest cost).

The location of the chargers can be varied: at home (garage residence or individual), at public areas (parking public, shopping center, supper market), or at specific charging stations (near highway, etc.). The normal charger can be deployed at customers home, at public areas or at a specific charging stations while the fast and rapid charger should be implemented at charging stations or public areas. Additionally, a potential place to put the charger is at workplace with the standard charger.

There are two business models for EV charging. The first one is called "Quick drop" model. In this model, the battery can be replaced by a full battery. Although it is quick, it is not a viable solution since a large back-up battery should be required (see Better Place project [2]). The second one is charging point and service supplemented. The service normally consists of a mobile or web-based application that allows the customers to find the appropriate charger point (location, price, place available). Also, additional services such as reservation or payment (e.g. via RFID tag, or prepaid service) can be provided. In this model, the service provider can buy energy from another energy provider, or it can be a energy provider [2].

In this paper, we only focus on the second model with the case of the individual EVs not for self-service electric cars. However, it is useful in some aspect for this type of service (e.g. mobility, communication aspect).

2.1.2 Typical usage of an EV regarding charging service

In order to give a better understanding of the typical electric vehicle charging process as well as the problems and challenges of this type of service, we would like to introduce two typical usage scenarios as follows.

David's normal day

Step 1: David lives in Nice and works at Sophia-Antipolis. At working days, he goes to work by his new electric car (EV). His car can go upto 80 km in a normal usage with a full battery. At David's garage, a normal charge was implemented. During the night, his EV is connected to this charger, and is automatically charged. The used electric is billed to the home electric consumption as another equipment under the contract with EDF [3]. Normally, the battery is full before going to work. It is the simplest way to charge his EV. When the energy cost is taken into account, David needs to find a suitable time to charge his EV. Since no intelligent mechanism is considered, he has to do it by hand.

The distance between David's home and workplace is about 27km. So, he can go to work and come back home with his EV without any energy problem, even if there is a traffic jam.

Step 2: Sometimes, David goes out for lunch in Antibes with his friends (about 20km for a round-trip). If he goes by his car, the EV may not have enough energy to come back home in case of traffic jam. So, he prefers to go by his friend's car.

[2] http://www.betterplace.com/

[3] Electricity of France: http://france.edf.com

Step 3: Recently, at his company parking area, the normal charging points have been implemented. This is provided by the service provider ABC. He registered to use the service and pay monthly for the used electricity. He got a card to use the service. Therefore, while at work, he can plug his EV in the charging point and leave it to charge. Now, he can go for lunch by his car! He can also use a mobile application provided by ABC to manage account status or to find a charging point or to make a reservation. His car can be charged during his lunch time.

Step 4: Today, he wakes up later than usual. So he do not have enough time to have breakfast. He arrives his company at 10h30. He realizes that he forgets his card at home. Thus, he cannot use the charging service at the parking area. So, he cannot go out for lunch in Antibes!

Step 5: As a normal working person, he leaves his company at 17h30 and gets home at 18h00. When he comes home, he always plugs his car into charging point and leaves it to charge to make sure that the energy is full before next morning. The evening is typically a period of high energy demand (peak period) since people return home and switch the electric equipment while almost the office/factory equipment is still running.

David's holiday

Step 1: This weekend David family goes to Toulon for sightseeing. He decides to go by his EV. As usual, his EV is full of energy this morning. He departs home at 7h00.

Step 2: Since Toulon is about 150 km far from Nice, he stops at Le Muy (75 km from Nice) to charge his car at a charging station near the highway. He goes to the charging station but at this time no place is available for his car. So, he has to wait for 20 minutes. Then, by using fast charging, it takes only 30 minutes to charge his car with full level of energy. David pays, for example, 10 euros for the charging by his credit card. Then, he goes to Toulon without any problem.

Step 3: He arrives in Toulon at 10h00. After few minutes to find an appropriate parking with charging service by using a mobile application, he pays 20 euros to fully charge his cars before coming back (around 18h00) for 16 kWh.

Step 4: After having an interesting time, David and his wife come back to the parking, and go home with his car.

2.2 Electric Vehicle Charging and Smart Grid

2.2.1 What are smart grids?

A smart grid is an electricity network which is able to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users by using information, communication and other advanced technologies. By doing that, it allows to co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability [6].

2.2.2 Why need to integrate EVs into smart grids?

Regarding a typical charging process, the EV is typically charged in the evening (period of high energy demands, or peak period) when the EV owners returns home. It makes the grid congested and therefore influences back to CO_2 emissions (related to the electricity generation by fuel type like coal, petroleum and natural gas) [13]. The EV can only help to reduce the CO_2 emission with an appropriate demand. Thus, the EV needs to be charged intelligently. Since the EV are parked 95% of the time [14], the EV integration into Smart Grid brings the benefits of enhancing the stability of the grid: i) The EV can be charged when the demand is low; and ii) The EV can be considered as a potential storage of renewable energy as well as a distributed energy source. Also, EV owners can earn benefits from Smart Grid advanced technologies to get better service (cost-effective, easy-to-use and secured transaction, etc.) [13].

2.2.3 Intelligent Charging Management

In the context of EV, the most important thing related to smart grid is intelligent charging management term. Intelligent charging management is a mechanism which allows the EVs to charge during off-peak periods (if possible) to minimize cost (from user side), to better power quality in the grid (from provider side) and for the system stability, reliability. Also, the EVs can feed power stored into the grid during peak periods (Vehicle-to-Grid, V2G or Vehicle-to-Home, V2H) with higher cost. Since the EVs are parked 95% of the time [14], the EVs is promising to become the distributed sources to add significantly to peak load.

With the intelligent charging management, the typical use cases of charging service is as described as follows:

- In the evening, when David returns home, normally, he plugs his EV into the electric outlet (charging point) and charges his EV during the peak period. By using the intelligent charging management, the EV will be charged during the night when the system load is typically low and at a low cost, while still ensuring the fully charged EV before it is used in the morning.

- While at work, the EV can be plugged into a charging point at company parking and can be charged throughout the day. The intelligent charging management again assures that the EV will have enough energy before it is used and will be charged during the off-peak time.

- During the charging period, the EV can feed power into the smart grid during the peak time (selling energy with high cost).

In order to efficiently integrate EVs into the smart grid, some aspects should be considered:

- EVs capacity management (battery state, energy demand);
- Management of the availability, location and capability of the EVs (related to mobility aspect);
- Load management on the grids;
- Communication between the EVs and Smart Grids (related to communication aspect);
- Optimization algorithm to to decide/calculate the charging schedule (requirements, constraints).

We also need to take into account the efficient battery usage (cycling power, cost and battery life).

2.2.4 Existing Proposals for Electric Vehicle Charging Service

Although there are a lot of publications about the electric vehicle charging system, a limited work considers it as a service. Document [15] outlines a set of service elements of a charging service provider: energy services, incidental services and add-on services. The energy services aim at supplying sufficient energy to the EV during the normal operation. The incidental services are executed when unexpected events occur (such as a quick charge) while add-on services provide additional ones (e.g., finding an available charging point). However, this work mainly emphasizes on mapping services into constraints in an EV-charging optimization algorithm.

About communication aspect, in [16] and [17] some access technologies (such as PLC, WLAN, GSM and xDSL) have been briefly introduced to gather data from the EV and the Grid for control purpose. However, only PLC is used for EV-Grid communication. Document [17] also considers roaming scenarios by using Session Initiation Protocol (SIP) to manage the session of the EV. Yet, SIP is only used for the session setup and control.

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.

2.3 Vision of the Electric Vehicle Charging Service

From a user point of view, the vision of the EVCS is described as follows:

- Service ubiquity: That means the users can access the service anywhere as the same way as at home (e.g., under only one contract). The used electricity can be automatically billed to the owner's account;

- An easy-to-use charging service: The EV owners no needs to provide any addition information to use the service. The charging constraints can be also easily set up if necessary (such as full charge before 7 am);
- Secured transactions;
- A cost-effective charge;
- A charging infrastructure information service (status and location) and an online management tool (for the reservation and consumption management).

From a provider point of view, the vision of EVCS is:

- Ensuring better power quality in the grid via a real-time interaction between the EV and the Smart Grid;
- Managing effectively user information (energy demand, consumption and location);
- Managing the availability, location and capacity available of the EV for V2G purpose;
- Integrating easily with the existing services.

3 Solution for Electric Vehicle Charging Service: Analysis and Use cases

Based on the vision of the EVCS, a solution for the future ECVS is proposed in terms of its design principles, operations and functionalities. Our solution helps to effectively manage a large number of EVs considering their mobility characteristics for the charging/discharging purpose. Furthermore, the mobility is hidden to the user and the provider. The general use cases then are presented to show the benefits of the solution.

3.1 Design Principles

For better understanding of the EVCS solution, this subsection helps highlight the characteristics of the solution which makes it different compared to the existing charging systems.

- Secured transaction based on the authentication/authorization procedure;
- Negotiation with the charging infrastructure before deciding to go to a specific station to charge. This procedure takes into account the status of both the EV and the Smart Grid;
- Flexible communication between the EV and the Smart Grid via different access technologies (WLAN/LTE and PLC);

- Cost minimizing by using the intelligent charging management (for user) while maximizing system reliability and stability (for energy provider);
- Transparent mobility for the user and the provider (roaming between stations under one service provider or different providers [18]);
- Easy-to-capture the user information for better control the load on the grid and for forecasting purpose.

3.2 Charging Service Operations and Functionalities

3.3 EVCS: Operations and Functionalities

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

3.3.1 (Session initiation) Authentication and context establishment (via WLAN/LTE/PLC)

This operation is executed when an EV is connected to the charging infrastructure for authenticating/authorizing and obtaining the EV profile.

3.3.2 Session negotiation (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 provider). It is noted that the this step is executed before reaching a charging station thanks to the wireless access technology for communicating between the EV and the charging infrastructure. Also, additional information of the station can be provided like discounts, bonuses, etc.

3.3.3 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 station 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).

3.3.4 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.

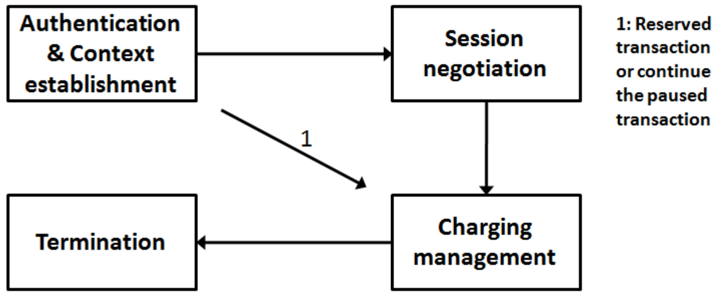

Figure 1: General Operation flows for charging service.

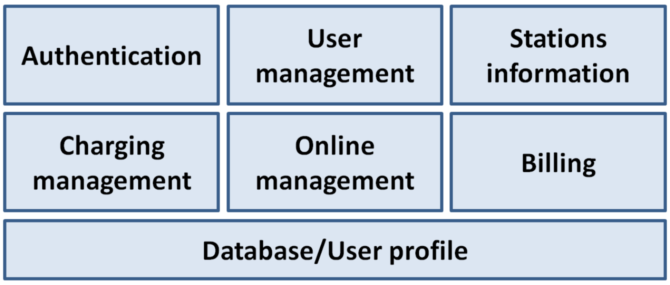

Figure 2: Charging service modules.

Therefore, the charging service can be divided into the basic modules as described in Figure 2. The main modules are listed as follows:

- Authentication module provides a secure mechanism to authenticate/authorize the EV (e.g., Authentication, Authorization and Accounting (AAA) mechanism);
- User management module manages the availability, location and capability of the EV (based on an IP mobility management protocol such as Mobile IPv6 (MIPv6) [19] and PMIPv6);
- Charging stations information manages all stations of the system (regarding their capacity, location, type of charger, availability and cost);
- (Intelligent) Charging management is the most important component of the EVCS. It decides the charging schedule based on the real-time interaction between the EV and the Grid;
- Online management module allows the users to manage the energy consumption, to make/cancel a reservation and payment;
- Billing module provides used electricity information as well as the user-related information;

- Database/user profile stores the user-related information (Identifier, energy consumption/demand, etc.). It can be co-located with the AAA server.

3.4 General Use Cases for the Electric Vehicle Charging Service

There are three general usage scenarios for the EVCS: charging at home, charging at a station and moving between the stations.

3.4.1 Charging at home

The network at home can be considered as home network of the EV. When the EV is plugged into the charging point at home, at first, the authentication service is executed to authenticate the EV via the PLC connection. The intelligent charging management then will be undertaken to automatically charge/discharge the EV to lower cost and effectively control/optimize the load on the grid. During the charging process, the EV can transfer data, synchronize with the personal computer or even access the Internet.

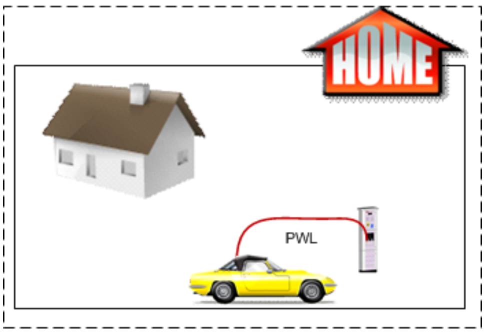

Figure 3: Charge at home.

3.4.2 Charging at a Station

At first, an EV can communicate with the charging infrastructure via the WLAN/LTE connection to authenticate/authorize the EV. The negotiation process then will be executed to propose an appropriate station as well as an appropriate charging session (session negotiation).

Based on the information proposed, the most appropriate station (with proposed session) will be selected to charge. It is noted that an additional cost may be added if the selected station and the home charging belong to different service provider (inter-domain mobility). The charging process can also be reserved. In this case, the EV simply needs to indicate the reservation number. The EV will be then plugged into the electrical outlet (using PLC connection) at this station. A vertical handover between WLAN/LTE and PLC will be performed that allows the EV to continue communicating with the charging station via the PLC connection. 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 provider's information (e.g., bonuses and charging station information, etc.). The station may also propose the EV to charge at another stations if its capacity/condition is not suitable for the EV demand with related information (location, condition and capacity).

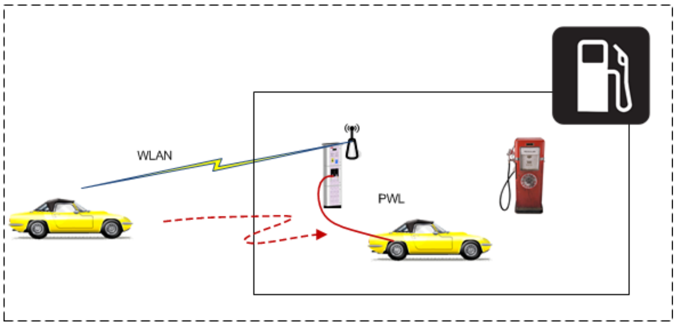

Figure 4: At a charging station.

3.4.3 Moving between the Stations

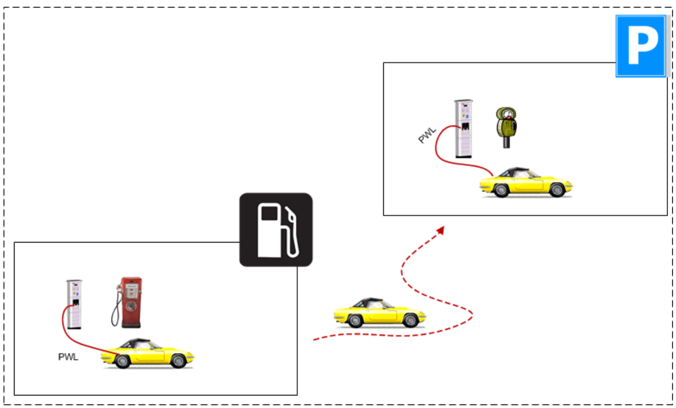

Figure 5: Moving between charging stations.

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

4 PMIPv6 for Electric Vehicle Charging Service

4.1 Why Proxy Mobile IPv6?

With its mobility characteristics, an EV can be charged at different places. Hence, an IP mobility solution (e.g., MIPv6 and PMIPv6 [9]) should be considered to bring better service. Since in EVCS, the mobility is transparent to the EV as well as for the service, the MIPv6 is not suitable for the EVCS for several reasons: i) The EV gets different IP addresses when performing handover; ii) The EV has to participate in mobility signaling. Unlike MIPv6, PMIPv6 is a good choice for the EVCS. It is because it makes heterogeneous communication technologies transparent to the EVCS and hides the mobility of the EVs to the service.

Proxy Mobile IPv6 (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 MIPv6, 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.

The centralized mobility anchor like Home Agent (in MIPv6) or LMA (in PMIPv6) may cause the well-known bottleneck and single point of failure issue since both MN context and traffic encapsulation need to be maintained at the mobility anchor. However, in the context of EVCS the amount of traffic from/to the EVs is supposed to be not much. The PMIPv6, with some enhancement mechanisms (traffic offload, load balancing), is able to deal with a large number of EVs.

As we can see in Fig. 6, using PMIPv6 offers some benefits in the context of EVCS:

- Integration with an AAA mechanism: PMIPv6 can co-operate with an AAA mechanism to allow authenticating/authorizing the EV at its home network as well as when it moves to a foreign network;
- EV-Grid interaction: The PMIP messages can be extended for collecting the EV-related information;
- Location management: It is used to provide location-related services as well as for EV-Grid interactions;
- 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;

- Context preservation: This feature facilitates the charging process of the EV in case of mobility.

Thanks to the advantages of PMIPv6, the energy and utility providers can provide an easy way but flexible to access their services.

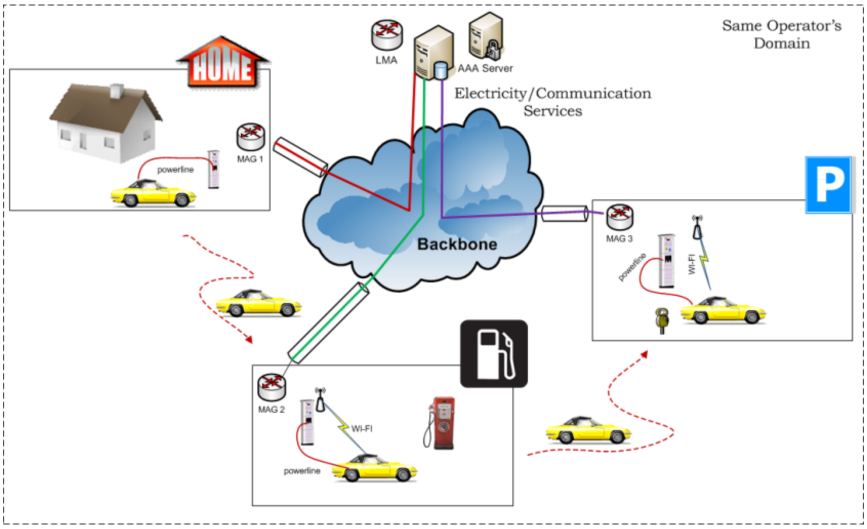

Figure 6: General usage scenario.

4.2 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. 7), the MAG communicates with the AAA server to verify that the MN is allowed to use the mobility service. Upon the successful authorization, the MAG obtains the MN profile (LMA address and some optional fields such as address configuration mode) from the AAA server. The MAG then sends a Proxy Binding Update (PBU) message to the LMA to get the Home Network Prefix (HNP) and update the current location of the MN. After updating its binding entry, the LMA replies by a Proxy Binding Acknowledgment (PBA) including the HNP allocated. The MAG then updates its binding entry for this MN. A bi-directional tunnel is established between the MAG and the LMA for redirecting the traffic from/to the MN. After that the MAG sends a (unicast) 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)(see Fig. 8), the pMAG signals the LMA and removes the binding and routing state for this MN. Once the MN is attached to the nMAG, the same process as described in the previous subsection 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 a RA 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. Also, a new bi-directional tunnel (LMA-nMAG) is established to route the traffic from/to the new location of the MN.

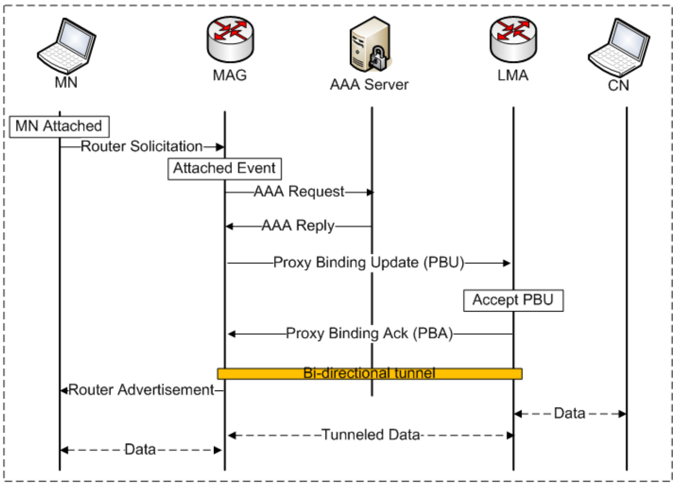

Figure 7: PMIPv6 registration signaling.

4.3 PMIPv6 for Electric Vehicle Charging Service

As described in Section 4.1, PMIPv6 can bring benefits to the EVCS. However, it has a few limitations. Thus, improvements are needed to make PMIPv6 suitable for the EVCS.

4.3.1 Handover across heterogeneous access technologies (WiFi, PLC): IPv6 Address Preservation

Our service requires the address preservation when the EV performs a vertical handover between the PLC and WiFi connection. There are several mechanisms to achieved this requirement.

- The fist mechanism uses a common identification for both interface PLC/WiFi (e.g. NAI [20]) to obtain the same prefix from the LMA/policy profile. Two interfaces also must use the same Interface ID (MAC address) to configure

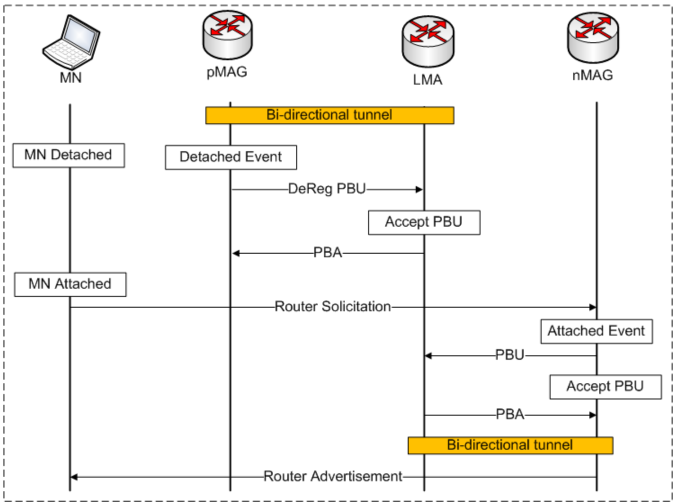

Figure 8: PMIPv6 handover signaling.

the same address. The limitation of this approach is that two interfaces cannot be active at the same time.

- The second one uses DHCPv6 mechanism. However, two interfaces are needed to set the same client_ID (for both stateful and stateless auto-configuration) [4]. In addition, in case of stateless auto-configuration, two interfaces also must use the same Interface ID (MAC address) to configure the same address. Again, two interfaces cannot be active at the same time.

- The third mechanism uses the logical interface technique [21] [22] which allows to hide the different access technologies by using a logical interface. As a result, the changing of interface is transparent to the IP stack (same IP address). This can be done by using Linux bridge [23] mechanism as illustrated in Fig. 9. Moreover, two interfaces can be active at the same time. For this reason, this method is more suitable than the others to facilitate the handover process in term of handover latency. Based on this method, the experiment will be made as in section 5.

4.3.2 Context Preservation

In order 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.

[4]http://www.rjsystems.nl/en/2100-dhcpv6-stateful-autocfg.php#cint.

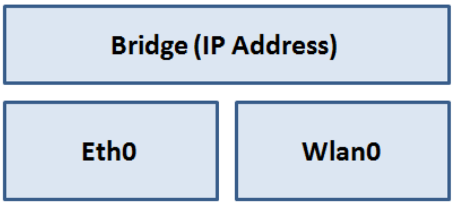

Figure 9: Logical interface mechanism with Bridge.

4.3.3 Inter-domain Mobility Support for PMIPv6

For the scenario of inter-domain roaming, an extension to PMIPv6 is needed to support inter-domain mobility. In [18], two possible approaches are described: fully distributed and partially distributed. This document shows that at this stage the partially distributed approach gives better performance than the other existing solutions and the fully distributed solution.

Once an MN enters its PMIPv6 domain, it gets a set of prefixes. Based on the prefix(es) allocated, the MN configures its IPv6 address(es). The MN then can use this address to initiate and maintain the sessions in a standard way while it remains attached to this domain. When changing its domain, the MN gets another prefix and configures its address based on this prefix. This address can be used to set up the new sessions. Until the previous sessions are not closed, the old address should be kept. Thus, a tunnel is built between the anchored LMA (A-LMA) and the current one to redirect packets between two LMAs using the old prefix. The main operation of the partially distributed solution is described as follows.

- *Registration* (see Fig. 10): When an MN is attached to a PMIPv6 domain, the standard PMIPv6 operations are executed. The LMA (LMA1) then sends a PBU to the Inter-domain Central Mobility Database (ICMD) which stores the information of mobility sessions of all PMIPv6 domains. This PBU includes the Mobile Node Identifier and Home Network Prefix options which are set to the MN's identifier (MN-ID) and the MN's prefix (Pref1), respectively. Since the session is new, the ICMD creates an entry which consists of the MN-ID, the Pref1 and the address of LMA1 in its Binding Cache entries (BCE). The signaling process and the BCE of the ICMD are described in Fig. 10.

- *Inter-domain operations (see Fig. 11)* : When the MN moves to another domain, the new LMA (LMA2 or S-LMA) allocates another prefix (Pref2) to the MN. Then, the S-LMA sends a PBU to the ICMD for the new prefix registration. Upon receiving the PBU and searching the BCE table, the ICMD updates the current location to the existing entries for the MN. It also creates a new entry corresponding to the MN-ID and the new prefix. The ICMD then sends a PBU including the S-LMA's address to the A-LMA (LMA1) to update the current location of the MN. Upon reception of the PBU, the A-LMA sets up its endpoint for bi-directional tunnel to the S-LMA, updates its BCE and routing for Pref1. The A-LMA also replies with a PBA to ensure that the new location of the MN has been successfully updated. Using a PBA, the ICMD then indicates the address of the A-LMA to the S-LMA, which performs the same process as that of A-LMA. Afterwards, a bi-directional tunnel is established between the S-LMA and the A-LMA to carry the traffic from/to MN using Pref1.

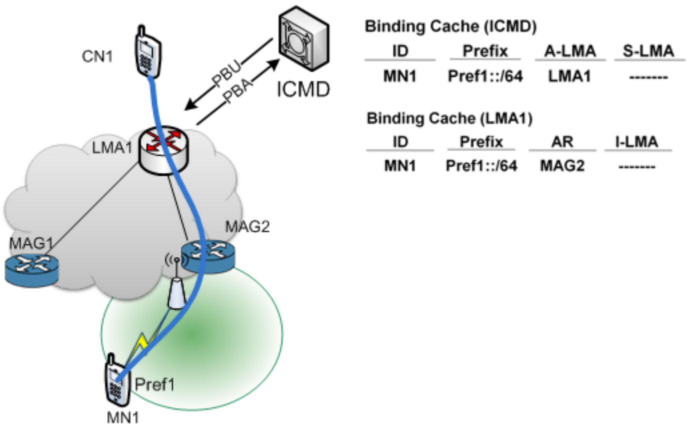

Figure 10: Inter-domain registration.

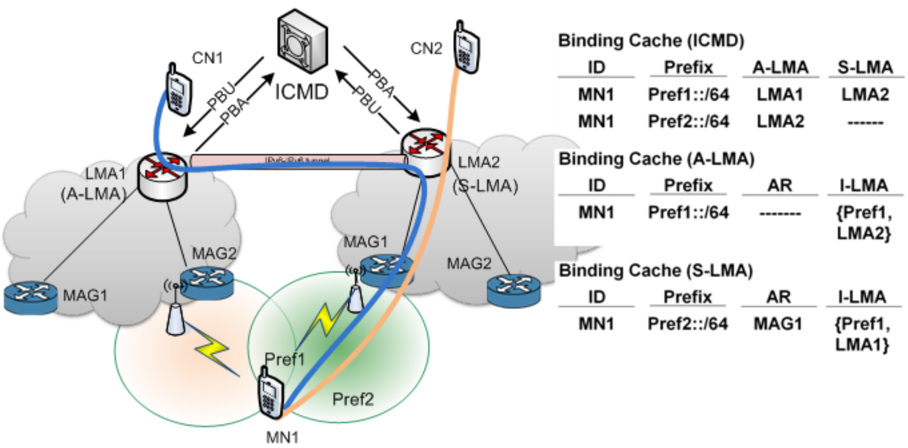

Figure 11: Inter-domain handover operations.

5 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.

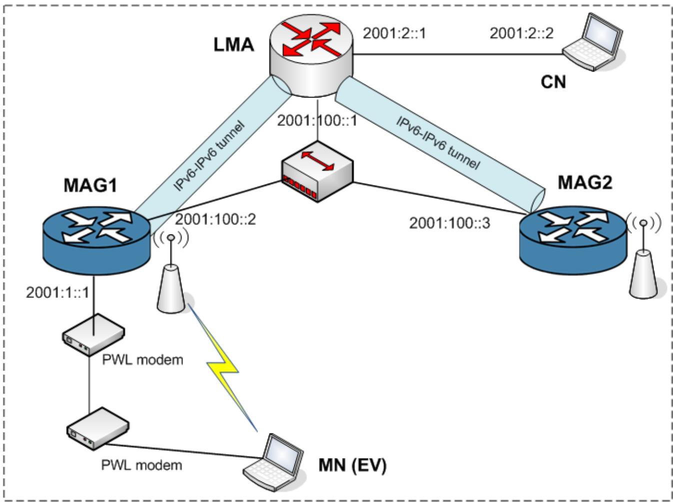

Figure 12: Testbed architecture.

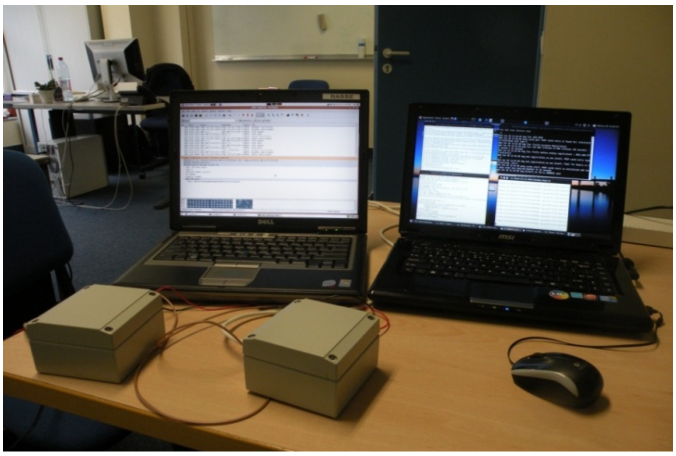

Figure 13: Actual image of the testbed.

5.1 Description of the Testbed

The testbed, as indicated in Fig. 12, 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) [24] to create the virtual machines. The LMA, one MAG (MAG2) and the CN are the virtual machines (UML) running on a host machine (running Ubuntu 10.04 LTS) 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. In order to connect the virtual machines, the virtual Ethernet connection is simulated by using a combination of Linux bridges and TAP interfaces. In case of PLC connection, two PLC modems are connected via coaxial cable and to the MN and to the MAG respectively. It is noted that thanks to VELCRI project, a real PLC connection is used in the testbed. In the testbed, the open source PMIPv6 implementation, named OAI PMIP [25], is used. The Linux kernel 2.6.38 which is re-complied to enable some required features for OAI PMIPv6 implementation, serves as the kernel for the PMIP entities. In our case, since the EV performs handover (roaming) between two different access technologies PLC and WiFi or between PLCs, layer 3 handover detection will be used (e.g. using RS message). As the EV is not aware of mobility, it will periodically send a RS via its active interface(s) (e.g. one message per second). Also, RADIUS protocol [26] is used as AAA service for this domain.

The actual image of the testbed is described in Fig. 13. In addition, the mapping between the actual image and the logical components of the testbed is illustrated in Fig. 14.

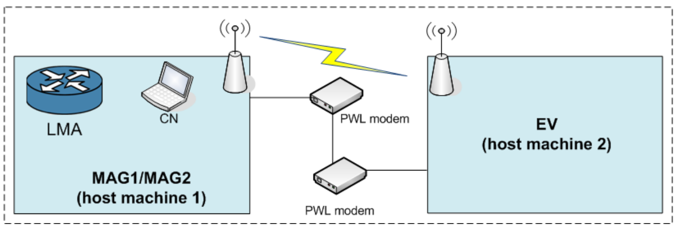

Figure 14: Mapping between the actual image and testbed components.

During the experiments, a network analyzer tool (e.g., Wireshark [27]) is used to capture the packets exchanged between the entities while a network testing tool (like Iperf [28]) to measure the throughput of WLAN/PLC connection. The Ping application plays the role of a simple service running on EV and CN.

5.2 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. The purpose of this scenario is to demonstrate that PMIPv6 can work correctly with PLC/WLAN. The EV's address configuration will be observed when it is connected to a MAG.
- Scenario 2: Vertical handover between WLAN and PLC at one MAG. The connection between the EV and the MAG is switched between PLC and WLAN. In the context of charging service, this scenario describes the transition between the negotiation, the charging management and the termination step.
- Scenario 3: (Horizontal) Handover/roaming between two MAGs (using PLC). In this case, the EV is first associated to a MAG via PLC connection. It then moves to another MAG (using PLC connection). From the EVCS point of view, this scenario represents the mobility of the EV between the stations.

6 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.

6.1 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 handover (scenario 2) as well as a horizontal handover between two MAGs (scenario 3), 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.

6.2 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) [29]. We can also 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.

The throughput achieved by using PLC connection is about 4.6Mpbs. This value is adequate for the normal traffic services.

Regarding handover latency in the scenario 2 (vertical handover between PLC and WLAN at the same MAG), since the two interfaces are activated at the same time, the handover delay is as similar to the time needed to update the EV location (interval 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 between MAGs using PLC connection), 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. 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). Thus, there is no need to store the EV's session information into the profile server. Vice versa, it can be considered as a handover between MAGs. In this case, the session information needs to be stored into the profile server. However, some experiments are required to select the most appropriate threshold value.

7 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 provider. Moreover, from a provider 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.

8 Acknowledgment

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References

References

[1] Wardsauto, "World Vehicle Population Tops 1 Billion Units", http://wardsauto.com/ar/world_vehicle_population_110815.

[2] M. Kearney, "Electric Vehicle Charging Infrastructure Deployment: Policy Analysis Using a Dynamic Behavioral Spatial Model", Master thesis, MIT, 2011.

[3] International Transport Forum,"Transport Greenhouse Gas Emissions: Country Data 2010", 2011.

[4] V. Bilotkach, and M. Mills, "Simple Economics of Electric Vehicle Adoption", Proc. of EWGT2012, September 2012, Vol. 54, pp. 979–988.

[5] S. Galli, A. Scaglione, and Z. Wang, "Power Line Communication and the Smart Grid", SmartGridComm, 2010.

[6] International Energy Agency, "Technology Roadmap: Smart Grids", April 2011.

[7] F. Nouvel, P. Maziero, and J. Prevotet, "Wireless and power line communication in vehicle", Design, Automation & Test in Europe, 2009.

[8] S. Barmada, M. Raugi. M. Tucci, and T. Zheng, "Power Line Communication in a Full Electric Vehicle: Measurements, Modelling and Analysis", ISPLC, 2010.

[9] S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, "Proxy Mobile IPv6", RFC 5213, August 2008.

[10] P. Sutterlin and W. Downey, “A Power Line Communication Tutorial - Challenges and Technologies”, ISPLC 98, 1998.

[11] E. Arabia, C. Ciofi, A. Consoli, R. Merlino, and A. Testa, “Electromechanical Actuators for Automotive Applications Exploiting Power Line Communication”, SPEEDAM, 2006.

[12] X. Feixiang, H. Mei, Z. Weige, and L. Juan, “Research on Electric Vehicle Charging Station Load Forecasting”, 2011 The International Conference on Advanced Power System Automation and Protection.

[13] International Transport Forum, “Smart Grids and Electric Vehicles: Made for each other?”, April 2012.

[14] N.S. Pearre, W. Kempton, R.L. Guensler, and V.V. Elango, “Electric vehicles: How much range is required for a day’s driving?”, Transportation Research Part C: Emerging Technologies, December 2011.

[15] O. Sundstrom and C. Binding, “Charging Service Elements for an Electric Vehicle Charging Service Provider”, in Proc. IEEE Power and Energy Society General Meeting, 2011.

[16] Z. Yuan, H. Xu, H. Han, and Y. Zhao, “Research of Smart Charging Management System for EVs Based on Wireless Communication Networks”, ICIAfS 2012.

[17] B. Jasen,C. Binding, O. Sundstrom, and D. Gantenbein, “Architecture and Communication of an Electric Vehicle Virtual Power Plant”,SmartGridComm, 2010.

[18] T. T. Nguyen and C. Bonnet, “DMM-based Inter-domain Mobility Support for Proxy Mobile IPv6”, WCNC 2013, April 2013.

[19] C. Perkins, D. Johnson, and J. Arkko, “Mobility Support in IPv6”, RFC 3775, July 2011.

[20] B. Aboba, M. Beadles, J. Arkko, and P. Eronen, “The Network Access Identifier”, RFC 4282, December 2005.

[21] T. Tran and Y. Hong, “Virtual interface for supporting multihoming and inter technology handover”, IETF-Draft (expired), April 2010.

[22] T. Melia, S. Gundavelli, “Logical Interface Support for multi-mode IP Hosts”,IETF-Draft (work-in-progress), October 2012.

[23] Linux Bridge, http://linuxfoundation.org/collaborate/workgroups/networking/bridge.

[24] User-Mode Linux, http://www.user-mode-linux.sourceforge.net.

[25] OAI PMIPv6, http://www.openairinterface.org/openairinterface-proxy-mobile-ipv6-oai-pmipv6.

[26] F. Xia, B. Sarikaya, J. Korhonen, S. Gundavelli, and D. Damic, "RADIUS Support for PMIPv6", RFC 6572, June 2012.

[27] Wireshark, http://www.wireshark.org/.

[28] Iperf, http://sourceforge.net/projects/iperf/.

[29] W. Wang, Y. Xu, M. Khanna, "A survey on the communication architectures in smart grid", In: Computer Networks, Vol. 55, Nr. 15 (2011) , p. 3604-3629.