eCo-FEV: efficient Cooperative infrastructure for Fully Electric Vehicles

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ABSTRACT

The electrification of road transport is considered a key element in Europe and worldwide for reducing the greenhouse gas (GHG) emissions in road transport. Electric mobility does not only cover the electrification of vehicles to Fully Electric Vehicles (FEVs), but also involve multiple infrastructure systems. The eCo-FEV project aims at achieving a breakthrough in FEV market introduction by proposing an IT electric mobility platform for integration of FEV into infrastructures, enabling connections and information exchanges between multiple infrastructure systems that are relevant to FEVs. The aim of this paper is to present the use cases and architecture defined by the project.

Keywords: eCo-FEV, Fully Electric Vehicle, communications, cooperative infrastructure

1. INTRODUCTION

Clean transportation represents a key economic and social contribution to the development of modern and future societies. In the context of economic crisis, European Union has identified “developing clean technologies for cars and construction” as one of the prioritized actions for economic recovery plan as emphasized in [1]. FEVs introduction has been announced by several car manufacturers, proposing a new environment friendly mobility mode. However, range anxiety is one main challenge for mass market introduction of FEVs. Users expect to be assisted in real time in order to avoid FEV energy shortage in case of unexpected traffic situation and energy provision. Furthermore, fast emerging smart city technologies integrate multiple social infrastructure systems in order to improve the societal efficiency such as energy management, traffic management etc. Therefore, it is natural to our perspective that integration of FEVs with multiple FEV relevant infrastructure systems will bring high
benefits in FEV introduction and in smart city development. The eCo-FEV project [2] aims at achieving a breakthrough for FEV introduction. The project proposes an IT electric mobility platform for the integration of FEVs into cooperative infrastructure systems. This IT platform will enable connection and information exchanges between multiple infrastructure systems such as road IT infrastructure, parking infrastructure, public transport operator and charging infrastructure. Such integration will further allow advanced telematics services to be developed for FEV users, thanks to the standardized vehicle to vehicle (V2V), vehicle to infrastructure (V2I) communication technologies and EV relevant standardized interfaces for information exchanges between stakeholders’ information systems. Furthermore, an important challenge of the project is the development of technical solutions to support static and dynamic contactless FEV charging capabilities. The present paper aims at providing eCo-FEV project up-to-date results in terms of use case definition and overall system architecture. Chapter 2 will present the methodology adopted by eCo-FEV project for definition of next generation E-Mobility platform. Examples of use cases selected by eCo-FEV project will be given in chapter 3. In chapter 4, architecture of the eCo-FEV system will be presented. As example of architecture design output of the project, architecture of the innovative charge while driving system will be presented. Finally, conclusion and introduction of future work are provided in chapter 5.

2. eCo-FEV OBJECTIVES AND APPROACH

The objective of eCo-FEV is to develop advanced E-Mobility platform that provides advanced FEV user assistance services to improve the FEV market introduction. In order to design such innovative and complex cooperative platform that may be deployable in real business implementation. Both technical and non-technical aspects need to be carefully taken into account. Therefore, it is important to define an appropriate methodology with basic principles before the system design. Following aspects are considered by the consortium:

[I]. User needs analysis: eCo-FEV system promotes user services for FEV user or FEV fleet operators to ease the usage and improve the efficiency of FEV, allowing the mass introduction of FEV and its integration into traffic flow. For this purpose, user needs analysis should be the starting point of the system design. This top down approach will enable identifying user requirements to the system, both from functional aspect, operational aspect and business and economic aspect. eCo-FEV project has defined a set of use case and related use case requirements. This work is used as input for system design, for business impact analysis and for test scenario definitions in the latter phase of the project.

[II]. System modularity and flexibility: eCo-FEV aims to develop a cooperative architecture in order to combine the information of several infrastructures for FEVs and users. It is the objective of the eCo-FEV project to propose this open architecture in order to enable the flexibility of the eCo-FEV concept in the follow up deployment in different implementation situations, e.g. implementation site requirements, specific use case
requirements, client requirements etc. It is important to underline that eCo-FEV functions may be distributed within more than one centers, and these functions may be delivered by various actors in one possible implementation. Some of such functions should be multi-instantiated (i.e. delivered simultaneously by multiple actors) during the deployment phases. The architecture has to support the possibility of multi-instantiation and multi-sourcing (i.e. various implementations) for these functions if necessary.

A modular architecture also enables the extensibility of the system to incorporate additional functionalities and services, while ensuring the backward compatibility of the system. This may be an important aspect to consider during the business model definition for a system targeting at converging the IT and vehicles technologies having high life cycle difference.

[III]. **Standardization:** In order to enable a modular system architecture design, standardization is playing an essential role. A standardized interface does not only ensure the communication interoperability between the communication parties, but also enables the extensibility and flexibility of the system. Both in ITS community and in FEV community, standardization activities are actively ongoing, with strong support from both public and private domains. eCo-FEV project targets at implementing standard compliant interfaces and functionalities for a set of existing standards, and providing contributions to ongoing standardization activities in relevant standardization organizations.

[IV]. **Business impact analysis:** Multiple stakeholders need to be involved in eCo-FEV’s decision making and investment procedure. Therefore, a business impact assessment is required. It can serve as groundwork for these stakeholders to estimate their business opportunities and risks. Generating this basis of decision making will help to overcome the limitations of interrelated singular actions. Therefore, multiple business domains have to be taken into consideration. eCo-FEV project will generate deeper insights by discussions with stakeholders. This will be used as a basis to design value networks and business models.

[V]. **Compliance and effectiveness assessment:** Multiple stakeholders are included in the eCo-FEV consortium in order to evaluate on site the telematics services and potential business models, including car manufacturers, traffic management operator, system provider, FEV service provider, energy trader and research institutes. The project is coordinated by Hitachi Europe Ltd and co-funded by European Commission. The services developed by eCo-FEV are going to be tested both in urban environments and highway situations on two test sites, with specific requirements and mobility needs, located respectively in France and in Italy. The French test site, provided by Conseil Général de l’Isère (French local road and transport manager) enables the experimentation of different advanced services for FEV users, including multi modal mobility services. This site includes a car park ride equipped with different types of conductive charging stations, with road side units and served by intercity bus lines. The operational traffic control center of Conseil Général de l’Isère provides real time traffic information to eCo-FEV system. Test activities to be carried by eCo-FEV project will cover both technical validation of the developed prototyped and the evaluation of system
and use cases effectiveness. On the other hand, standardized testing specifications are important to enable standard compliance or even system performance test. eCo-FEV project may provide inputs to standard bodies regarding the testing activities.

3. eCo-FEV USE CASES

By making the infrastructure systems and FEVs cooperate with each other, advanced telematics services for FEV users will be enabled, allowing FEV users to quickly react on the driving situations and efficiently manage the charging during the whole trip, meanwhile trying to satisfy the travelling needs (e.g. arrival time) and economic needs (e.g. charging cost) of FEV users.

As starting point, it is important to define the scope and border line of the eCo-FEV system. The principal functions offered by the eCo-FEV system will be the trip planning and assistance during the trip. The system will help travelers to respect the planned itinerary and, if necessary, to adapt it to environmental changes monitoring the FEV autonomy. In order to guarantee this the pillars of the system will be:

- Charging and parking facilities booking and accounting;
- Optimal balance between usage of individual FEV and public transport;
- Rapidity of trip reconfiguration according to the traffic events;
- Real time information (events and location based information) provision.

Based on such scope definition, different external actors of eCo-FEV system have been identified, including customer side (eCo-FEV traveler, FEV, FEV delivery fleet operator), existing infrastructures systems (road infrastructure operator, public transport operator, parking facility operator, energy provider, weather info provider, map service provider, charging facility operator etc.) or business operation actors (banking service operator, etc.). These external actors interact with eCo-FEV system in different circumstances and situations (i.e. use cases). An external actor may send a request, provide information to eCo-FEV system or receive services from the eCo-FEV system.

In a typical trip assistance use case, eCo-FEV system collects real time information from the external actors, including user travel request, user preference, FEV real time position and battery State of Charge (SoC), as well as real time information from relevant infrastructure systems e.g. traffic condition, weather condition, charging facility availability, parking facility availability, public transport information etc. With the collected information, eCo-FEV system is able to realize some advanced data mining and data aggregation functionalities, to dynamically estimate the FEV remaining range and potential impacts of an event to the original FEV trip plan, e.g. traffic jam, weather condition, charging facility availability change etc. Then eCo-FEV system may provide dynamic navigation assistance to user to adjust the travel and charging plan accordingly, e.g. search alternative itineraries, search other charging facilities or propose FEV users to use other transport mode. Some examples of use cases considered in eCo-FEV are summarized in Table 1.
<table>
<thead>
<tr>
<th>Table 1. eCo-FEV use cases</th>
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<td><strong>Charging Spot (C/S) POI notification</strong></td>
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<tr>
<td><strong>Trip assistance</strong></td>
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<td><strong>Dynamic traffic event notification</strong></td>
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<td><strong>Vehicle relationship management</strong></td>
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<td><strong>Charging assistance</strong></td>
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<td><strong>E-mobility in co-modality</strong></td>
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<td><strong>FEV fleet management</strong></td>
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<td><strong>Monitoring user case</strong></td>
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It should be noted that, eCo-FEV system is not limited to any specific list of use cases neither to any specific list of functionalities. Even though efforts are made to identify most relevant use cases that potentially bring important benefits to FEV users along the usage of FEV, eCo-FEV system should be able to support other services or be connected with additional external infrastructure systems or with other user types.

4. eCo-FEV SYSTEM ARCHITECTURE DESIGN

Based on use case definition, overall architecture of the eCo-FEV system can be defined. Different viewpoints are used to define the eCo-FEV system architecture e.g. system viewpoint, communication viewpoint, information viewpoint, technology viewpoint or functional viewpoint etc. The target of the architecture design is to identify functional elements and allocate them to different actors (sub systems) of the eCo-FEV system, in order to guide the system specification work in next phase.

From system viewpoint, the eCo-FEV system architecture is illustrated in Figure 1. The eCo-FEV system is composed of the following sub-systems:

- **On Board Unit (OBU):** OBU is integrated in FEV. It includes communication hardware (e.g. Wi-Fi, UMTS, G5…), application unit hardware, vehicle gateway to
interface with FEV electronic system, at least one HMI device and the in-vehicle charging systems (e.g. inductive power transfer, conductive power transfer, etc.).

- **Road Side Unit (RSU):** RSU is installed at road side. It includes communication hardware (e.g. Wi-Fi, UMTS, etc.), application unit hardware and potentially gateways to interface with road side equipment or with charging infrastructure. It may provide local services to FEV users or play the role of communication bridge between mobile devices and backend infrastructure systems.

- **eCo-FEV backend:** eCo-FEV backend is a backend system that includes at least a middleware platform for infrastructure data collection and potentially data aggregation functionalities, and one service provider platform that provides FEV services to customers. Additionally, and according to the business strategy, other platforms may be included in eCo-FEV backend such as an ID provider platform that manages the ID and contract information of the customers.

Multiple communication media may be used (cellular networks, European ITS G5 technologies, wired communication etc.) to enable communication to and from the eCo-FEV backend. In order to support various applications, the eCo-FEV platform accommodates a common set of functionalities to preliminary process the received data or to provide data management functions.

**Figure 1: eCo-FEV general architecture**

- **Charging infrastructure:** charging infrastructure includes EV supply equipment (EVSE) at road side for EV charging and a backend operator (EVSE operator). eCo-FEV backend receives real time charging facility availability information from charging infrastructure sub system. In the scope of eCo-FEV project, either existing charging infrastructures are used e.g. conductive charging, or new charging
infrastructure is built e.g. charge while driving infrastructure. For this reason, charging infrastructure is included as eCo-FEV sub system. In another implementation, charging infrastructure may be considered as external actor of the eCo-FEV system, similar to other infrastructure systems e.g. road IT infrastructure. Additionally, it should be highlighted that, eCo-FEV system architecture should not be limited to any specific charging infrastructure. The eCo-FEV project targets at developing a standardized interface with different charging infrastructures.

From communication viewpoint, multiple communication media will be used in eCo-FEV, satisfying communication needs among sub systems and with external infrastructure systems. On one hand, dedicated ITS communications based on 5.9GHz (ITS G5) is used to enable ad hoc communication between FEVs and between FEV and RSUs. On the other hand, legacy communication network such as cellular network and Internet are used for communication between FEV to backend and between infrastructure systems. One of the technical challenges is to enable continuous connectivity of FEV to backend. Depending on the radio coverage of the area where the FEV is localized, FEV will be able to switch from an Access Network to another (handover) in order to stay connected. The continuity of the connectivity will be ensured by the use of IPv6 protocols that provide mobility support, such as Mobile IPv6 and Network Mobility (NEMO) protocols. Additionally, functionalities are required to dynamically select the appropriate media and communication path to establish communication, based on requirements set by application.

From information viewpoint, the architecture design challenge comes from the requirement of its flexibility necessary to fit various business models. To meet these challenges, on one hand, the eCo-FEV system has to propose an integration bus with a set of new services, on the other, it has to respect already existing standardized interfaces supported by the existing information systems. For this purpose, eCo-FEV has identified a set of relevant interfaces that should be exposed by the system, for example:

- Web service interface for communication between FEV and eCo-FEV backend;
- Open interface to enable user authentication assuming the separation of ID provider (e.g. an OEM that wants to control the customer information) and service providers;
- DATEX II [3] interface that enables the exchange of traffic information between traffic management centers and between RSU and backend systems;
- Interface that enables charging infrastructures to provide real time charging facilities availability information to eCo-FEV backend;
- Standardized messages that enable local information provision between vehicles and between infrastructure to vehicles via Cooperative ITS, such as a POI message that provides charging spot availability via wireless communications [4];
- Interface for Vehicle to Grid communication as standardized in ISO 15118 [5];
- Open interface between application platform and middleware platform, enabling application providers to request support or retrieve data from middleware platform.
- M2M interface that enables message exchanges between eCo-FEV backend and FEV;

Some of the above mentioned interfaces are already standardized (e.g. C-ITS communication) and even deployed (e.g. DATEX II). These interfaces will be implemented in eCo-FEV system. For other interfaces, either extensions are required to the existing standards, due to the new technical challenges, or standardization seems missing to our best knowledge. For example, ISO 15118 standards only cover specifications on data exchange using Power Line Communication (PLC) technology. eCo-FEV will extend this standard to support the inductive charging, in particular the charge while driving technology. Another example is the M2M interface and web interfaces, it seems that standardized exchange message model does not exist to enable data exchanges between FEV and backend for certain basic user cases e.g. FEV data collection, backend navigation assistance, etc. These identified standard gaps are also reflected similar study done by relevant standard bodies e.g. in [6]. eCo-FEV project will be able to provide technical specifications to relevant standard bodies as dissemination.

From functional viewpoint, a high level functional architecture of the eCo-FEV system is defined in order to allocate main functionalities to sub systems. This high level functional architecture is illustrated in Figure 3.

![Figure 3: eCo-FEV system high level functional architecture](image)

As shown in Figure 2, eCo-FEV backend provides trip and charging assistance services to assist FEV before and during trip. For this purpose, eCo-FEV backend manages relevant information from FEVs and collected from infrastructure systems. eCo-FEV backend may apply data aggregation functionalities for collected data. Furthermore, eCo-FEV backend manages the identity and access rights for FEV users according to the defined business model. OBU receives information from eCo-FEV backend and realizes navigation applications. RSU is equipped at road side, allowing provision of local information to FEVs or providing communication capacities for road side equipment/charging equipment and FEVs.
This high level functional architecture will enable detailed design of information exchange flow for each eCo-FEV use case. This sequence diagram design will enable the identification of messages (type and content) to be exchanged between eCo-FEV sub systems and with external infrastructure systems. Furthermore, following this step, detailed functional design of each eCo-FEV sub system is realized, enabling the identification of functional components included in each sub system for further specifications work. As one example and one of the technical challenges of the project, the basic architecture for the charge while driving (CWD) system is illustrated in Figure 3.

![Figure 3: CWD overall architecture](image)

At FEV side, a wireless charging device will be developed and integrated, to receive energy via wireless energy transfer link. OBU also includes an implementation of the ITS stations to integrate communication and application capacities for eCo-FEV use cases. At infrastructure side, the charging infrastructure includes two main parts: charging equipment EVSE that is mounted at road side; and a backend system EVSE operator. EVSE is further composed of HW components for the electric power transfer, it will be purposely realized and coordinated with the one mounted on the FEV. One of the components to be added in EVSE is the charging station control unit that manages the V2G data exchanges with OBU and with EVSE operator. It is the communication counter part of EVSE operator. EVSE operator is a backend system that manages the operation of EVSEs. It manages the Authentication, Authorization, Accounting (AAA) procedure for FEV charging and monitors the charging process from backend. EVSE operator provides charging facilities status information to eCo-FEV backend. For charge while driving developed in eCo-FEV project, RSU may be used as alternative of PLC technology for conductive charging, in order to facilitate charging data exchanges between OBU and EVSE. RSU is therefore used as router. ITS G5 is candidate...
communication media, with additional challenges e.g. security, data transfer latency etc.

5. CONCLUSION AND FUTURE WORK

eCo-FEV system is a complex IT system that involves multiple systems, actors and stakeholders both in terms of technical and non-technical aspects. Architecture design of such system requires consideration of multiple aspects such as standardization, interoperability, modularity and extensibility, integration with existing systems, user needs and business requirements etc. Multiple technical challenges are identified e.g. connectivity, new charging modes, data mining etc. Technical solutions provided to these challenges may further improve the business potential of eCo-FEV system and thus the mass introduction of FEVs.

At the writing time of the present article, eCo-FEV consortium has selected a set of representative use cases that may be provided by the eCo-FEV system, and further realized the functional design of the eCo-FEV system and sub systems.

In the next steps, we will focus on detailed specifications and development of the eCo-FEV systems. Meanwhile, eCo-FEV project will continue the testing plan and testing specification works, in preparation of system validation and use case evaluations and demonstrations. Additionally, eCo-FEV project will input technical specifications as disseminations to relevant standard organizations to fill up identified standards gaps, which is an important dissemination task of the project.

6. ACKNOWLEDGMENT

This work has been co-funded by the European Union’s 7th Framework Programme for Research, namely through the eCo-FEV project (No. FP7 314411). The authors wish to acknowledge the European Commission’s support. We also wish to acknowledge our gratitude and appreciation to all eCo-FEV project partners for their contributions during the development of various ideas presented in this paper.

7. REFERENCES

[5] ISO 15118: Road vehicles -- Vehicle to grid communication