combining infrastructures for efficient electric mobility

Deliverable D400.3

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1.0	19.05.2015	Final version
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1.2	06.06.2015	Final version after notes by Programme Officers (rev. by CG38/CGI, HIT)

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1 Executive Summary

The eCo-FEV project aims at achieving a breakthrough in Fully Electric Vehicle (FEV) introduction by proposing a general service platform for integration of FEVs with different infrastructure systems cooperating with each other – thus allowing precise FEV telematics services and charging management services based on real time information.

The general concept of eCo-FEV is based on the development of innovative next generation electric mobility (E-mobility) infrastructure by mutual system cooperation among FEV and independent FEV-related infrastructures being networked. The cooperative E-mobility infrastructure enables the information collection from independent infrastructure systems and provides data aggregation functionalities to enable also cloud based high quality FEV services for FEV users.

A set of sub systems has been identified and developed during WP3 according to the two different scenarios, wireless charging and conductive charging. These sub systems are interacting with each other, and with different FEV related infrastructure systems. A set of common services has been developed for FEV user or FEV fleet operator to improve the FEV usage efficiency in real travelling and traffic situations. The eCo-FEV system architecture has been integrated starting from the defined sub systems, namely in vehicle On Board Unit (OBU), road side unit (RSU), charging infrastructure system and eCo-FEV backend sub system and the technical validation has been performed.

In this deliverable the technical evaluation of the overall system is reported; although the main focus has been based on the evaluation of developed ICT services, with related functionalities, and on the communication between backend, EVSE (EV supply equipment), FEV, also Inductive Charging functionality has been evaluated in laboratory tests.

For performing the technical evaluation, the methodology described in D400.1 and D400.2 has been adopted.

2 Introduction

An iterative approach has been followed among WP200, WP300 and WP400 to ensure systematic and thorough testing and evaluation of the eCo-FEV system.

The eCo-FEV components have been developed and validated within WP300 according to the Specifications and use case identified in WP200. The evaluation and validation methodology have been identified in WP400 and further tests and the final evaluation have been performed with the main objectives to ensure that the envisaged system is properly working and to assess whether it may have a positive impact on the transport system.

Considering the commonly used “V” Model in this approach [1], depicted in Figure 2.1, eCo-FEV’s WP400 is mainly concerned with the *Unit Testing*, *Subsystem Verification*, *System Verification*, and *System Validation* phases, as indicated with orange markers in the figure.

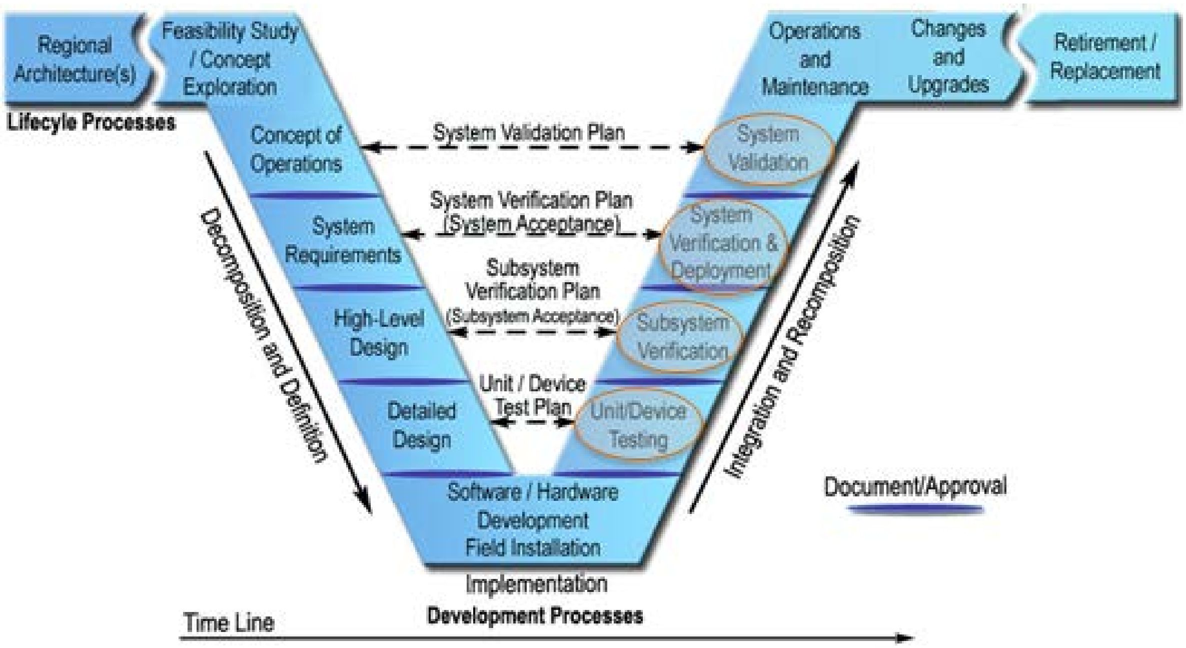


Figure 2.1. Main phases of the generic systems engineering approach [1]

The left side of the V model represents the system decomposition and requirements definition, followed by product and process design; while the right side represents system production, integration and verification.

Our system is an artefact created by involved partners, that consists of components or blocks that pursue the common goal of eCo-FEV according to the mentioned aims of the project, that cannot be achieved by each of them separately; the analysis on the effect of the systems are included within the D400.4.

As well known, in a system we may include software and hardware, operated by people (experts) who are the integrating and intelligent (ITS) part of the system itself: each component of the system and its behaviour are strictly connected to the other components. Yet, being some parts in a research phase, their test is intrinsically carried out within the laboratory and occasionally in the test site, while being some others at an applicative level, their tests consist in the starting test and functional operation; all the components or subsystems, speaking with the Systems engineering approach, need an functional testing that would require a more or less extended operation; a parallel may be taken with complex systems as transportation ones (e.g. a metro), where the functional testing implies not rarely 6-months of operation by staff, before being accessible for public transport.

According to this process, the evaluation started with the *unit testing* of low-level individual components of the eCo-FEV system defined in D200.3, to verify the internal functionality of each component and.

Once the individual components are verified, they are integrated to form the subsystems specified in the high-level design in D200.2, which will then be evaluated in the *subsystem verification* phase in order to confirm that all interfaces have been correctly implemented and all requirements have been satisfied for each subsystem.

The *system verification* phase is concerned with the evaluation of the system as a whole, ensuring that the system behaves as expected, taking the use cases defined in D200.1 as the main input.

According to eCo-FEV architecture the subsystems defined within the project development are:

- On-Board Unit (OBU)
- Charging Infrastructure (CI)
- Road Side Unit (RSU)
- eCo-FEV Backend

Each subsystem is divided into different components; for each sub system the validation checks the correct implementation of all developed components and, during the sub system integration phase, the interfaces among these components; the interactions among all eCo-FEV subsystems and any other external entities have been verified during the system validation stage.

Systems Engineering has emerged in direct response to the increasing complexity of systems. It has been adopted within eCo-FEV, as its purpose requires, is an interdisciplinary approach (TUB, HIT, POLITO, CRF, CEA, REN, mainly) which concentrates on developing and organising artificial complex systems. This approach standardises the flow-down and traceability of specifications for complex products from customer requirements through production, operation, and disposal, passing through test and maintenance phases. In this sense it integrates all of the disciplines and specialty groups forming a structured development process ("top-down" approach).

Substantially the approach followed for the eCo-FEV development in the Italian and the French test site was similar on a high level, that means in the first phase of abovementioned top-down approach. The major differences are related to the wireless charging infrastructure developed at the Italian test site. That is quite new so developed mainly in the laboratory, while at the French test site the conductive charging infrastructure solution has been adopted, yet remembering the specific innovation associated to the new ITS services as the booking, the remote visibility of parking areas for electric charging, the routing and scheduling associated to the route planner once the driver wants to know the available places for charging. The algorithms, that were out in the scope of the project, but necessary for the application of mentioned functions, are typically based on di routing and scheduling, developed by Hitachi on the navigator functions: they are mixed algorithms which require the minimum path with time window constraints, both on the arches (travel times, possibly variable with traffic conditions) and the nodes (time for recharging [see D.400.4] which vary themselves on the kind of recharging [e.g. Grenoble] , rapid or not, static [Grenoble] or in motion [Susa, POLITO] and related queues). A point of strength of eCo-FEV is implicitly the reduction of times in nodes and the optimised choice of travels based on waiting time besides than on minimal paths.

In Deliverable D300.5 the overall validation activity and results are reported; while the validation tests at the Italian test site were completed as triggering tests and implicitly continuously carried out as regards the CWD, in the French site they were completed as regards the starting tests, preliminary as regards a statistical analysis of a long-lasting functional tests, as abovementioned using metros as examples. Therefore, the major activity for the final evaluation report has been performed in the French test site. However the wireless charging functionality has been deeply tested in laboratory and evaluation is reported, yet not preventing the functional tests from future evolutions.

3 System architecture

A high level architectural overview of the eCo-FEV system is illustrated in Figure 3.1.

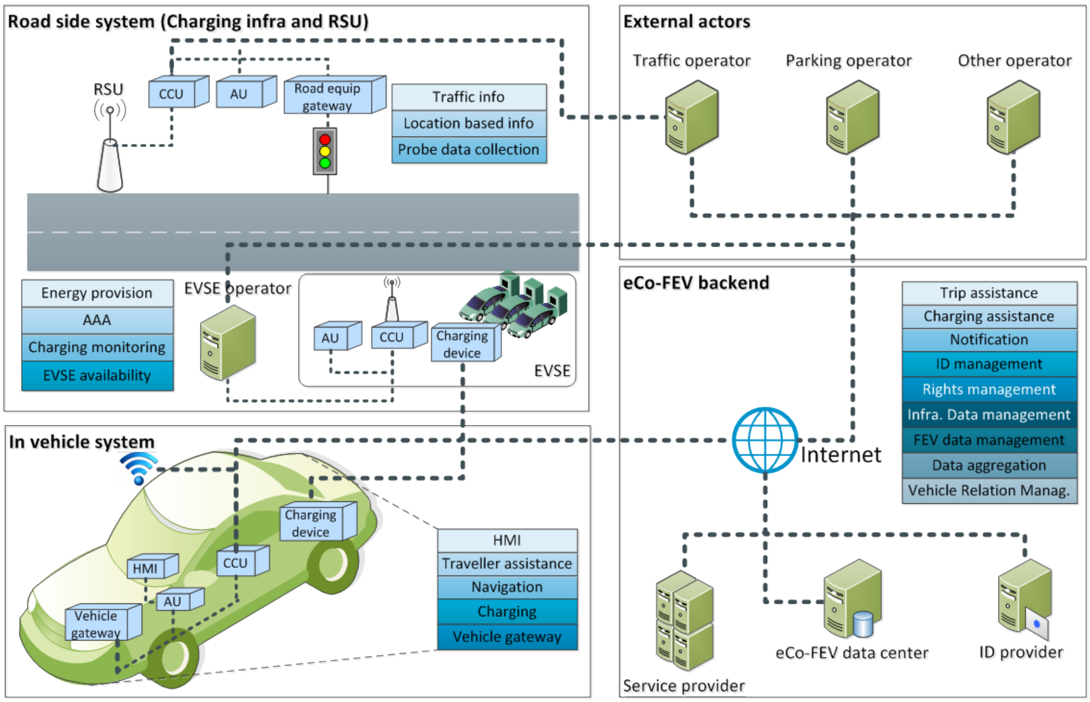


Figure 3.1. eCo-FEV system high level architecture and subsystems

The eCo-FEV system includes 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.). The OBU provides telematics services (ITS) and charging assistance for FEV users.
- **Charging infrastructure:** charging infrastructure includes EV supply equipment (EVSE) at road side for EV charging and a backend operator (EVSE operator). EVSE includes communication hardware (e.g. Wi-Fi, UMTS, etc.), application unit hardware and energy provision equipment (inductive power transfer or conductive power transfer). EVSE operator is in charge of managing, operating and monitoring EVSEs. EVSE also provides services to assist the FEV charging process such as Authentication,

Authorization, Accounting (AAA), charging monitoring etc. The EVSE Operator is the backend of the charging infrastructure. It communicates with a set of charging station control units, for gathering monitoring and status information, and triggering some actions (such as booking or remote visibility of empty spaces for charging and booking, as mentioned above). It implements the Server-side of the AAA for the charging process. On the other hand it communicates with the eCo-FEV backend for reporting the status of the charging facilities (monitoring) and providing accounting information.

- **Road Side Unit (RSU)**: A RSU includes communication hardware (e.g. Wi-Fi, UMTS, etc.), application unit hardware and potentially gateways to interface with road side infrastructure or with charging infrastructure. The main roles of RSUs are: traffic information broadcasting (traffic events, traffic conditions, and estimated travel times), personalised service information (subscription, user request, information supply) and location based non-safety information broadcasting (EVSE status, real time information from Transport Public Management Center, road signage information).
- **eCo-FEV backend**: eCo-FEV backend is a backend system that includes at least a middleware platform for infrastructure data collection and data aggregation functionalities, and one service provider platform that provides FEV services to customers.

eCo-FEV subsystems interact with each other in order to realize electric mobility services.

4 System validation

4.1 OBU-Renault technical validation

As mentioned in previous project deliverables the On-board Unit (OBU) offers communication and application capabilities to all other devices present on board. The OBU contains the CCU (communication control unit) designated also as a Mobile Router (MR), the application unit (AU) and the HMI device (Figure 4.1).

The MR is in charge of purely telecomm functionalities, the AU deliver the ICT services in charge of the applicative dialog with the eCo-FEV backend and HMI provide the end user functionalities.

The ICT services cover:

- "Probe message" periodically emitted by the FEV to inform the eCo-FEV backend about the FEV status and its geographical position;
- Initial route, route updates communicated by the eCo-FEV backend to the FEV.

The end user functionalities deliver the navigation interface and route guidance based on the information delivered by the ICT services.

The RM and AU functionalities are placed on Linux industrial PC and the HMI on the Android WI-FI enabled tablet. In the eCo-FEV environment the HMI delivers the navigation interface.

Two aspects were validated during the tests:

- Reliability and performance of ICT services and communications between car and eCo-FEV backend
- Navigation interface behaviour in the context of routes calculated by the eCo-FEV backend.

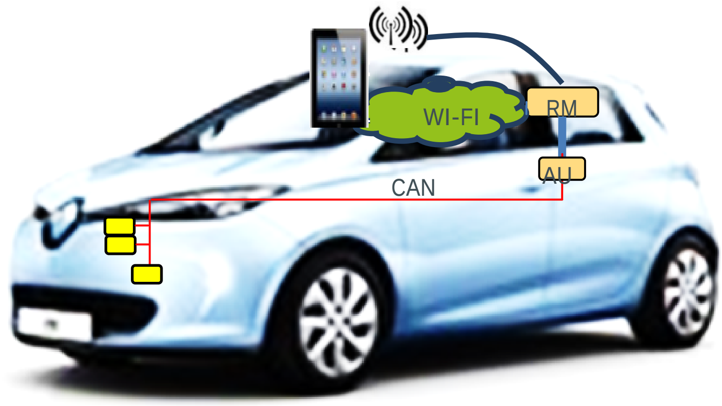


Figure 4.1. On Board Unit

4.1.1 Mobile router

From a communications standpoint, a Mobile Router is part of a larger communication system architecture containing many access network technologies as well as links to Internet. The Figure 4.2 depicts the system deployed for the project. On the road, one can identify electrical Recharging Stations, 4G cellular network access as well as 802.11p Road-Side Units and an 802.11ac Hotspot.

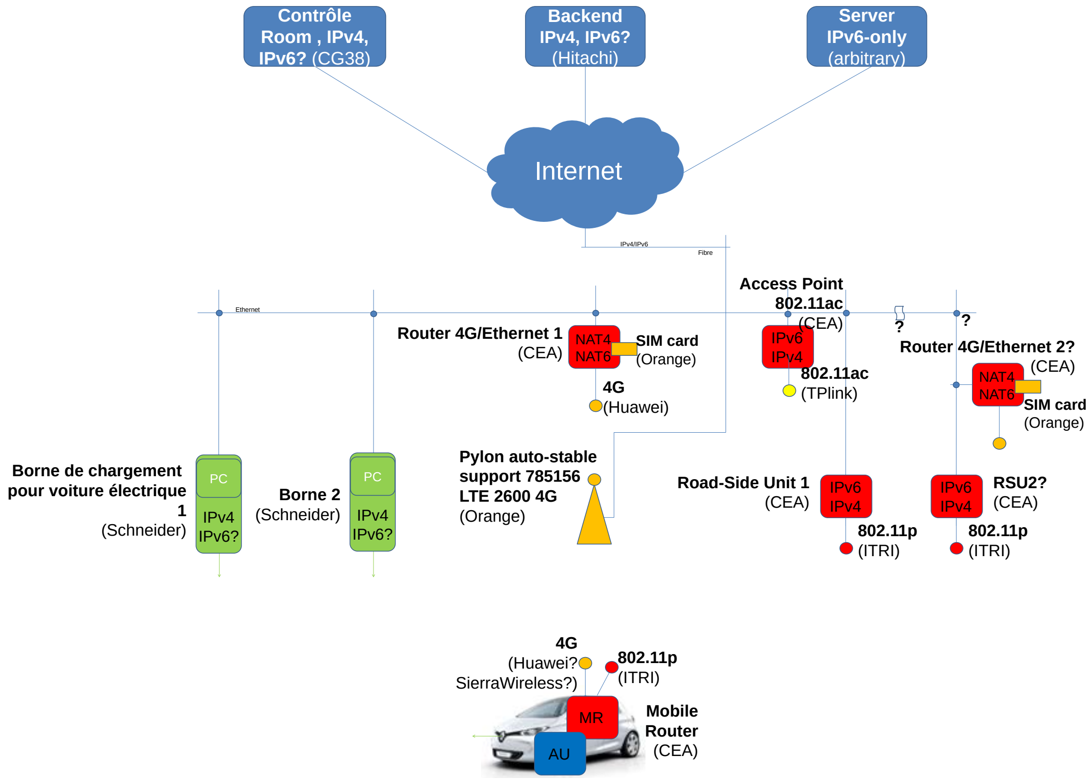


Figure 4.2. Overall Communications Architecture for On-board Unit (Mobile Router) in Vehicle

In this communication system architecture realised various tests and we demonstrated the communication capabilities delivered by the mobile router:

- Transparent IPv4 and IPv6 communication for all on board device connected by the Ethernet or the on board WI-FI;
- Transparent handover between 4G and 802.11p without inducing any interruption in the application flow executed by any on board devices.

4.1.2 AU tests

The test demonstrates the possibility of the AU (application unit) to communicate with the eCo-FEV backend:

- vehicle relationship probe messages delivered by car to the eCo-FEV backend;
- routing information exchange to enable the navigation functionalities executed by the HMI device.

4.1.3 HMI and user experience tests

The end user interaction with the system was tested from the HMI Android tablet connected by the car WI-FI to the AU. We tested the eCo-FEV capacity to deliver the routing information to the locally executed navigation. We demonstrated that the system architecture was able to deliver the routing and navigation information with the performance compliant with the driving constraints. Special attention was paid to the cohabitation of the on board navigation capacities and the routing functionalities offered by the eCo-FEV backend. We demonstrated that the on board navigation was able to consider the eCo-FEV backend generated routes as soon these routes were delivered.

4.2 OBU-CRF technical validation

The architecture implemented in the CRF vehicle for the wireless charging case is illustrated in Figure 4.3; it was designed taking into account constrains related to the existing vehicle electric/electronic architecture, the opportunity to use the existing proprietary Blue&Me telematics device for developing dedicated features (as vehicle CAN networks gateway), and the requirements coming from wireless charging functionality.

The communication with the backend has been developed in an Android based tablet and the communication between the vehicle and the charging infrastructure (V2G) is done by a CAN-WiFi gateway device (Cohda on-board); the communication functionalities have been evaluated within the Italian test site integration and results have been reported in D300.5.

Some HW components have been integrated within the existing FEV equipment (high voltage battery, inverter and traction motor): a power device, containing a high frequency caption coil (secondary coil) and power electronics, connected on the high-voltage (HV) DC bus with the existing HV components (battery). The charging functionality has been evaluated in laboratory.

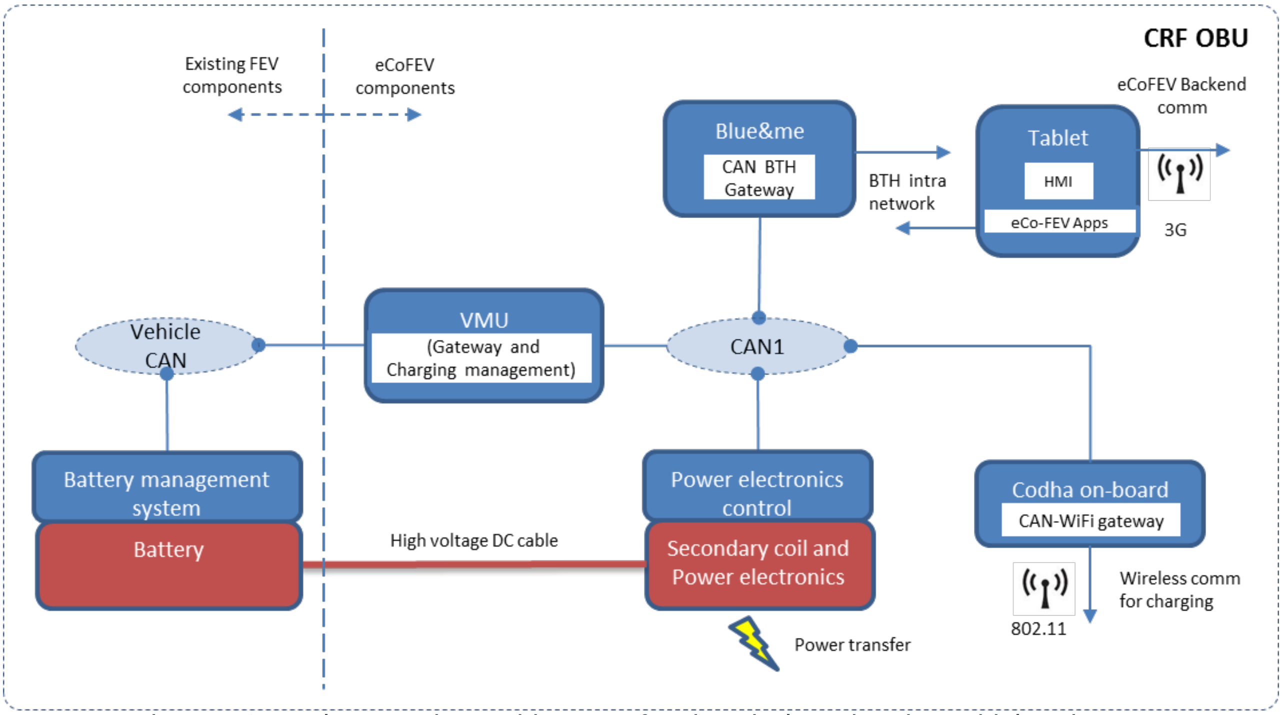


Figure 4.3. Implementation architecture for the wireless charging vehicle subsystem

The interface with the FEV CAN is done by an ECU (VMU – Vehicle Management Unit) which has two main functions:

- CAN gateway device - collects and processes data from the vehicle CAN bus network, (i.e. battery SOC, instantaneous power consumption, etc.) and transfers them to a dedicated CAN1.
- The data displayed by the HMI (Tablet) from the CAN1 are transferred by the Blue&Me, proprietary FIAT /FCA telematics ECU, using a Bluetooth interface.
- Charging management - a finite state machine is implemented in order to manage the wireless charging process and error handling and to send notifications to the HMI.

The adopted HMI consists in a tablet that should be considered as a fixed touchable dashboard embedded in the vehicle dashboard.

During the development all the java API for the communication between the OBU and the backend (basically the WebSocket and CoAP protocols) were acquired and tested with some modification in an Android app (EcoFevDroid) in the tablet.

During the integration of the HMI functionalities in the Android app the communication functionalities and the logic behind were maintained active with the assumption that if the performance of the app had been downgraded such functionalities would have been moved in a standalone app in an additional laptop.

At the end of the development almost no reduction of processing capability were noted for what concerns both the communication with the backend and the interaction with the driver. The only delays noted in the visualisation of the maps were due to the connection with Google maps service.

The next figure (Figure 4.4) shows the subcomponents of EcoFevDroid and the interactions with other components. All the HMI graphic components are organised as views and run in a single UI thread. The main subcomponent is the EVService that is created and activated as soon as the EcoFevDroid is activated. The communication between all the subcomponents takes place by means of the LocalBroadcasting Android bus. The EVService is an Android sticky service which is active until the TourApp is terminated by explicitly selecting and confirming the Exit with the Exit button.

The EVService contains the following subcomponents:

1: SPP manager manages the communication with Blue&Me. The signal values are forwarded to the other components via LocalBroadcasting as soon as they are received.

2: TTS controller manages the text-to-speech control of the messages associated with the FEV status and events coming from the backend and Blue&Me.

3: SignalsLogger is in charge of the file storage of all the signals acquired by the FEV

4: BackendConnector is responsible for the connection to the eCo-FEV backend by means of coap and WebSockets messages.

5: StateMachine manages all the states and events foreseen for the normal and charging status of the FEV.

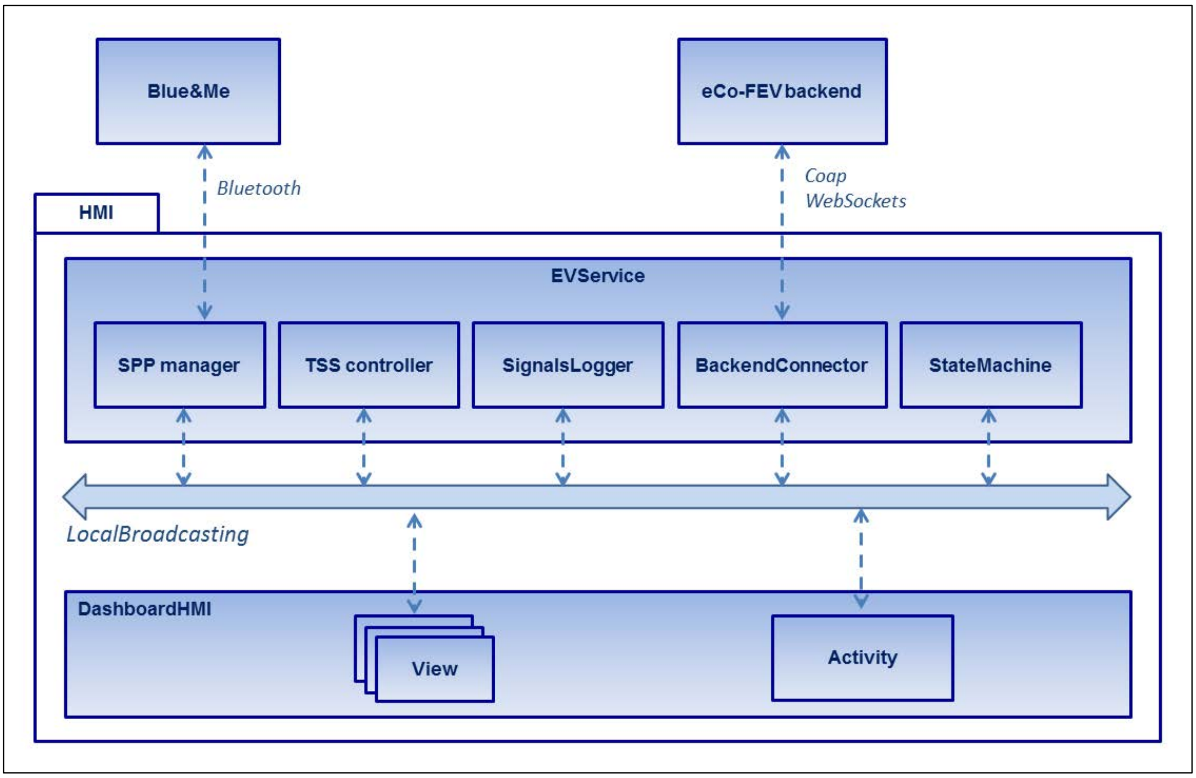


Figure 4.4. HMI architecture

Test Id	Test case Description	Expected Result	Result
1	All the signals coming from Blue&Me and the GPS sensor are acquired both in static and dynamic FEV status.	The values shown in the HMI must be the same as the equivalent values in the FEV.	Passed. Test done by means of visual check using CANalyzer tool on a PC and the tablet.
2	FEV status update. During static and variable (dynamic) driving conditions, the tablet sends the FEV status update CoAP message to the backend.	The log available in the backend monitoring page should reflect the data sent by the FEV	Passed. Test done by means of visual check and manual comparison by means of log files on the tablet.
3	Route acquisition. A target charging spot is defined by accessing the backend web page. Then, the tablet acquires the route.	The route shown by the HMI should be comparable to the route visible in the related backend web page	Passed. Test done by means of visual check.
4	Rerouting. A traffic event is simulated in the current route. The backend reacts by elaborating a new route that is sent to the tablet.	The new route shown by the HMI should be comparable to the route visible in the related backend web page	Passed. Test done by means of visual check.

Table 4.1.HMI functional test

For the communication between the FEV and the infrastructure a vehicle gateway application has been developed; it is based on the MK3 Cohda Wireless board and implements a wireless ieee802.11p gateway that connects the CAN buses of a vehicle within a road side unit or another vehicle. The structure of wireless messages exchanged between the two stations is compliant with the ITS-G5 ETSI standard[1].

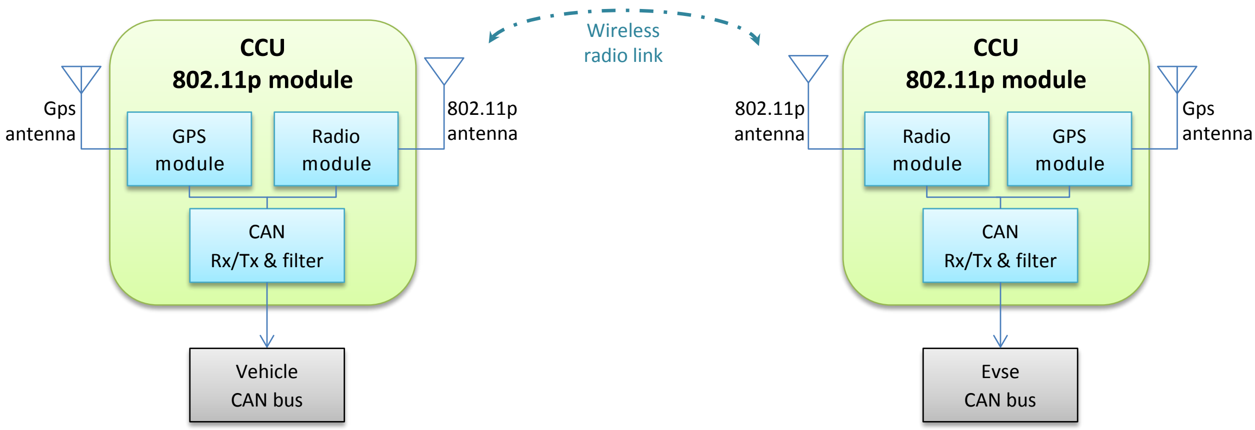


Figure 4.5 Virtual connection between vehicle CAN bus and Evse bus

The Cohda Communication Unit is equipped with three main blocks, listed hereafter.

- A radio module: in charge of the wireless communication according to the ETSI specification;
- A GPS module: in charge of time synchronization and geo-localization of the station;
- A CAN module: in charge to collect vehicles' messages from CAN bus.

Whenever a CAN message is generated from the vehicle or from the road side units it will be intercepted by application and if the message is compliant with a specified communication database it will be broadcasted through the wireless ieee802.11p radio channel.
This filtering operation allows exchanging only those vehicle messages that are of interest for the eCo-FEV application.
On the other side, whenever a wireless message is received from a communication station it will be directly forwarded to the vehicle or Electric Vehicle Supply Equipment (EVSE) CAN bus.
In addition to that the two stations periodically send a broadcast informative message with vehicle's information.

[1] ETSI TS 102 637-2: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

The informative message is known as Cooperative Awareness Messages (CAM) and provides information about: presence, positions as well as basic status of the station to neighbouring units that are located within a single hop distance.

According to the ETSI standard, CAM messages have a generation rate of 1Hz. In the eCo-FEV project the communication units read from these messages the identification ID and the updated position of the transmitting station. Knowing its position and the current location of the vehicle/road side unit the station is able to calculate the distance between the two stations.

The information related to the distance between the vehicle and the charging units is used in order to prepare the road side unit for the authorisation process and all the pre-charging operations required to perform a safe recharging.

The presence of a vehicle or a recharging road side unit is notified by a specific CAN message. Through this informative message the EVSE architecture is able to detect the approaching of an electric vehicle that should be recharged.

	FEV-ITS G5 station (RSU)
Latency	ITS-G5 communication is characterized by latency below 100ms.
Packet Loss	The ITS-G5 channel does not provide packet retransmissions but since the communication between vehicle and RSU occurs at very short distance (about 50 m) the packet error probability is very low and can be managed from EVSE station.
Network Coverage	The Cohda Wireless unit is equipped with a radio module able to operate in 2x2 MIMO mode, 30Mhz of bandwidth and maximum transmitting power of 30dBmW. Providing the MK5 module with 5dBi antennas the two units mounted on the test site are able to communicate without any losses at a distance of more than 300 meters in open-field conditions. In any case it is possible to reduce the reception area to the desired geographical region from configuration file.

Table 4.2. FEV-RSU communication

4.3 eCo-FEV Backend Technical Validation

As mentioned in previous eCo-FEV deliverables, eCo-FEV backend connects with FEV and other infrastructure systems via Internet domain. eCo-FEV backend functionalities are implemented in different layers and may be implemented in more than one physical entity i.e. backend servers.

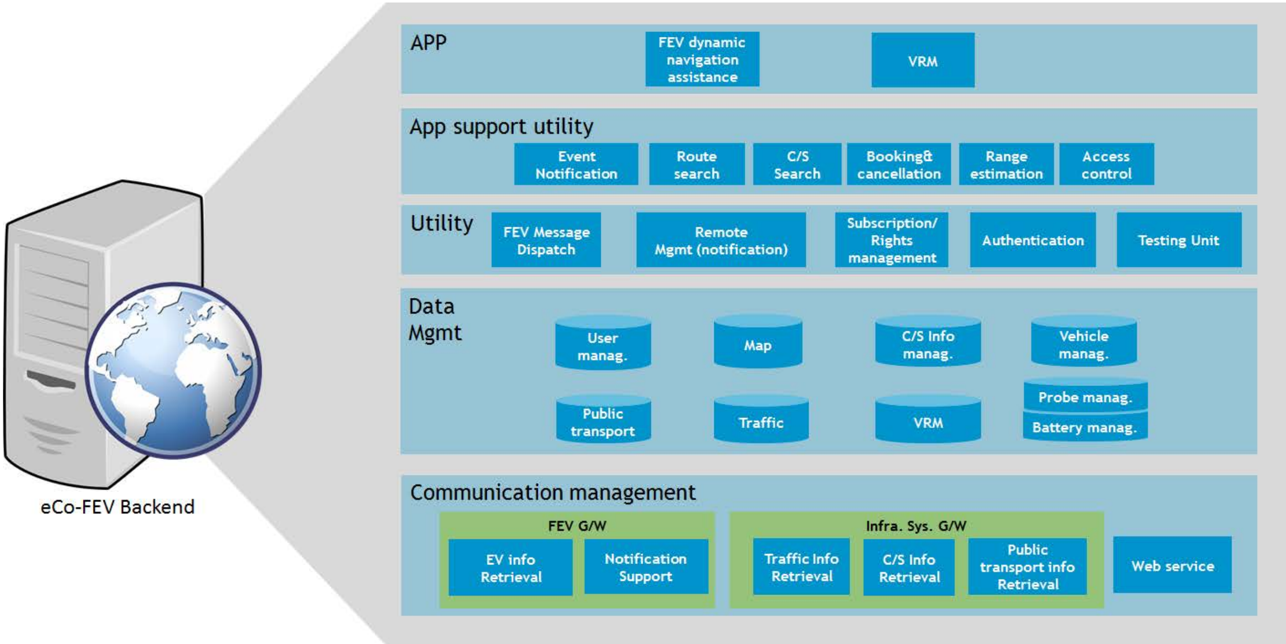


Figure 4.6. eCo-FEV backend sub system overall architecture

eCo-FEV backend is composed by different sub-layers, listed hereafter.

- Communication management: This layer is devoted to the exchange of information with FEV and other infrastructure;
- Data Management: This layer deals with the storage of the data which are collected or calculated by the backend;
- Utility: This layer contains a series of functionalities to support the execution of the backend. In particular, user management, authentication and testing are part of this layer;
- Application Support Utility: This layer supports the applications with common functionalities;
- Application Layer: This layer contains the services running on top of the backend.

Additionally, the backend is providing user and administration graphical user interface to exploit the services of eCo-FEV and to administrate the backend.

The purpose of eCo-FEV backend technical validation is to confirm that the developed eCo-FEV subsystem behaves as specified in D200.3. The validation of the eCo-FEV backend subsystem therefore consists of the validation of eCo-FEV backend communication interfaces and of the internal components.

In the communication interface tests, each interaction of the backend with the other sub-systems of eCo-FEV was tested. The tests were executed validating the following messages or data.

- Message format: For each interface the usage of the correct message type was confirmed and validated;
- Data correctness: For each data field the constraints have been checked and validated;
- Message flow accordingly to specifications: Following the specified sequence diagrams the flow of messages has been checked.

As regards the internal component, the following functional validation tests have been performed on the database side:

- Database validation to check consistency between specification and implementation;
- Functional verification of the routing algorithm running with pgRouting;
- Connectivity between database engine and web application

Finally, regarding web application, the scope of the validation has been to verify that the logic described in the sequence diagrams of the specification document were properly implemented.

4.4 Charging Infrastructure validation

We recall that the Charging infrastructure System in eCo-FEV covers two power transfer technologies (conductive power transfer and inductive power transfer) that contain inherent differences not only regarding the power transfer itself, but also regarding the consequences on the ICT systems operating the different technologies. At the same time the different technologies need to exhibit analogical functionalities and services provided to the e-mobility stake holders, such as user and / or Fully Electrical Vehicle (FEV) authentication and authorization, charging session accounting of the users or the FEV and then reporting the Charging Data Records (CDR) to the respective energy provider, reservation services for users and or electro mobility providers, and monitoring of the Electric Vehicle Supply Equipment (EVSE), on one hand for the owner or operator of the EVSE, to make sure that the equipment is working correctly and to be informed if it is not the case, and on the other hand to inform the other electro mobility stake holders about the status of the EVSE such as availability information and necessary technological parameters for the service provision.

These services are provided by the charging infrastructure system over different chains of interfaces using different technologies. Thus the overall quality of the services is then dependent on the performance of these interfaces and technologies used. Since the architectural choices of the charging infrastructure system define and describe these interfaces and technologies, a short recall of the architecture as described in D300.5 is revised.

4.4.1 Short description of the Charging Infrastructure Architecture

The charging infrastructure architecture is composed of two different components the Charging Station Control Unit (CSCU) and the Electric Vehicle Supply Equipment Operator (EVSE-Operator). The CSCU is a hardware installed on site at the EVSE and the EVSE-Operator is merely a service (more precisely a set of services) deployed in a server infrastructure. These two components cooperate together to provide the different services such as Authentication, Authorization and Accounting (AAA), Monitoring (both technical monitoring and availability monitoring), and Booking (reservations of charging facility for EV users).

The EVSE-Operator communicates to the different CSCUs on the different Sites on one hand and in his turn, provides a set of services for the eCo-FEV Back End over a Representational State Transfer (REST) Web Service. Although the interface to the eCo-FEV Bach End is unified the communication to the CSCU depends on the different charging technology for which the CSCU has been developed.

In general the CSCU needs to interface with the EV or its user for authentication and authorization triggering when the EV or EV’s user requests to charge. This is both the case for inductive and conductive charging. Furthermore it is useful that the CSCU has a communication link to the EVSE-Operator in order to check the AAA data of the EV user requesting the charging service. The communication to the EVSE Operator is also needed to provide information about the status of the EVSE especially for the operating staff of the EVSE-Operator but also for providing the E-mobility providers with accessibility and availability information. Last not least the Interface between the EVSE-Operator and the EVSE is needed for propagating reservations for certain EV users. The technologies used to provide these different services over the CSCU-EVSE-Operator interface differ between the two test sites, since they were developed for the two different technologies. Moreover the CSCU preforms the operations and services related to the control of the power transfer transparently to the user however in coordination with the power electronics installed in the EVSE.

For the inductive charging technology on the Susa test-site, the CSCU has been developed in eCo-FEV from scratch. Thus there were no specific limitations on the interface(s) between the EVSE-Operator and CSCU, nor any limitations on the technologies used over these interfaces. As described in D300.5 the CSCU at Susa test-site for inductive charging uses Remote

Authentication Dial In User Service (RADIUS) protocol for AAA, and Simple Network Management Protocol (SNMP) for Monitoring and Booking. Aside of the CSCU – EVSE-Operator interface, the CSCU, on Susa test-site, interfaces with the EV and the Power Electronics over a serial CAN-Bus interface. This interface is not only used for the Charging Procedure Control (CPC), but also used by the EV to trigger the charging request.

In contrary, for the conductive Charging solution deployed in Grenoble test-site, a commercial solution was installed. This means that the CSCU represents the microcontroller inside the commercial EVSE, which transparently handles the CPC once an EV is charging. Nonetheless to start a charging session the CSCU interfaces with the user that needs to hold the Radio Frequency Identification (RFID) badge in from of the CSCU's (or EVSE's) reader. Furthermore the commercial EVSE has a single interface that uses Open Charge Point Protocol (OCPP) currently in the version 1.5, over which the EVSE-Operator can communicate to the EVSE's CSCU to provide all the services described before. E.g. for authenticating a user's RFID trigger, the ID of the RFID is then communicated by the CSCU to the EVSE-Operator, over the OCPP interface. The OCPP interface further sends status information and Meter Values for the ' charging sessions.

Even though the CSCUs use different technologies the functionalities are analogical. The EVSE-Operator has to implement the counter parts of these technologies to provide the functionalities and services of the CSCUs. Furthermore the different technologies used by the different CSCUs when communicating with the EVSE-Operator, are then aggregated at the EVSE-Operator that implements a single REST-based interface, over which E-mobility providers (such as eCo-FEV back End) can access the services of the charging infrastructure. In the following section the validation of the components and subsystems will be described.

4.4.2 Validation of the CSCU for CWD

Subsystem	Charging Infrastructure
High level component	CSCU
Test ID	Functional Test
Involved subsystems	CSCU – VMU – PE (Road) – PE (On board) – ANPR camera – EVSE-Operator

Test case Id	Test case Description	Expected Result	Actual Result	Remarks
1	CAN communication to the PE (Road)	Send and receive CAN Messages to and from the PE (Road)	PASS	
2	CAN communication to the PE (On Board)	Send and receive CAN Messages to and from the PE (On Board)	PASS	
3	CAN communication to the VMU	Send and receive CAN Messages to and from the VMU	PASS	
4	ANPR Data acquisition	Acquire the plate number from the ANPR camera	PASS	
5	Sending Monitoring information	Monitoring information available upon request	PASS	
6	AAA communication	ADIUS implementation on the CSCU sends authentication Request and accounting Messages	PASS	
7	State Machine validation	Stand-alone validation of the state machine according to the specification	PASS	

4.4.3 Validation of the functionalities for the conductive charging

Subsystem	Charging Infrastructure
High level component	AAA, Monitoring, and booking
Test ID	Interface Test for OCPP
Involved subsystems	Conductive CS – EVSE Operator

Test case Id	Test case Description	Expected Result	Actual Result	Remarks
1	Dynamic IP address acquisition for the Lab-Charging station	Get the right IP address that could change dynamically in order to address the SOAP messages to the charging station SOAP Endpoint Address	PASS	This Test is Only needed for the Lab-Charging station, for the station deployed on the test-sites, probably not needed
2	Boot-Notification Message	If the Charging Station ID is known/Expected by EVSE-Operator, an acknowledgement is sent back with the value of the heart beat interval. If not, the EVSE-Operator replies with a negative acknowledgment and the CS stops sending messages to the EVSE-Operator	PASS	
3	Heart-Beat	CS sends periodical messages to the EVSE-Operator	PASS	
4	Status notification	CS notifies EVSE-Operator in case of status changes or errors.	PASS	
5	Authentication Request	CS sends the ID of the users to the EVSE-Operator, which an grant or deny access to the CS.	PASS	

6	Start Transaction	CS notifies EVSE-Operator that a charging session for a previously authorized User has started	PASS	
7	Meter Values	CS sends the Meter values periodically to the EVSE-Operator	PASS	
8	Stop Transaction	CS informs the EVSE-Operator that a charging session has stopped, with the total amount of charged energy	PASS	
9	Get Configuration	The EVSE-Operator queries the CS for a specific configuration value, or for all the values	PASS	
10	Change Configuration	EVSE-Operator changes a configuration value on the Charging Station	PASS	

4.4.4 Validation of the common functionalities

Subsystem	Charging Infrastructure
High level component	AAA
Test ID	Functional Test
Involved subsystems	CSCU – EVSE Operator

Test case Id	Test case Description	Expected Result	Actual Result	Remarks
1	CSCU_AAA ID acquisition	Right ID of FEV can be acquired at the AAA front End	PASS	
2	CSCU_AAA authentication request	Make sure that the interaction between the two AAA Components result in either success or reject, in case the ID is authorized or not, respectively.	PASS	
3	EVSE_Operator_AAA authentication response		PASS	
4	EVSE_Operator_AAA Accounting	Actually charged energy in KWh can be determined and retained at EVSE-Operator	PASS	

Table 4.3. AAA functional test

Subsystem	Charging Infrastructure
High level component	Booking
Test ID	Functional Test
Involved subsystems	CSCU – EVSE Operator

Test case Id	Test case Description	Expected Result	Actual Result	Remarks
1	Booking routing	Booking request (or Cancellation) is routed to the respective C/S CU	PASS	

2	Booking execution	The C/S CU locks the Charge Point for the respective FEV ID	PASS	
3	Booking timeout	The C/S CU cancels the booking in case the FEV does not show up at the respective Charge Point after a given timeout	PASS	

Table 4.4. Booking functional test

Subsystem	Charging Infrastructure
High level component	Monitoring
Test ID	Functional Test
Involved subsystems	CSCU – EVSE Operator

Test case Id	Test case Description	Expected Result	Actual Result	Remarks
1	AAA Status	CS/CU sends the AAA status to the EVSE-Operator including the logged (charging) in FEV ID and their meter values	PASS	
2	CPC Status	The CS/CU send the CPC status to the EVSE operator including the power at which the FEV is charging, the internal status the CPC State, and eventually the electrical failures in case they occur (CB, RCD …)	PASS	
3	Booking status	The Monitoring component retains the information of the bookings and booking cancellations	PASS	

Table 4.5. Monitoring functional test

Subsystem	Charging Infrastructure
High level component	Web Service
Test ID	Functional Test
Involved subsystems	EVSE Operator – eCo-FEV BE

Test case Id	Test case Description	Expected Result	Actual Result	Remarks
1	Information retrieval from the EVSE-Operator Component	Necessary Information available at the EVSE-Operator Components are represented at the Web Service Component	PASS	
2	Interface with the eCo-FEV Backend	Web Service implementation according to the agreed Interface as described in D200.3	PASS	

Table 4.6. Web service functional test

5 System performance evaluation

This section provides the performance evaluation of the overall eCo-FEV system.

5.1 Key Performance Indicators

In this section, a list of performance indicators for the quality assessment is reported.

It must be noted that due to limited availability of vehicles and charging infrastructure, besides possible tests in time, the result of the analysis is only qualitative and cannot be statistical. Additionally, since no user tests have been performed, some of the results are not available.

In order to complete the performance evaluation of the system, a piloting project can now be expected to carry out a complete functional test.

Performance Indicator	Description	Target Value / Range	Observed Value or Behaviour
Average time spent for eCo-FEV registration	The overall time required for a user to fill in all required fields and successfully register for eCo-FEV	TBD. Device dependent (PC, tablet, OBU, etc.)	N/A No test on user experience has been performed
eCo-FEV Backend Message process latency	Average time difference of probe management database update time and VRMessage time stamp	≤ 10 s	This metric is calculated as the sum of each of the following process times: 1. Message generation time in OBU. VRM message, generated every 2 seconds in presence of GPS coordinates, this time is the sum of: 1) the CoAP message generation evaluated in about 5 ms, 2) the transfer time between the HMI process and the OBU communication service evaluated in less than 10 mw and finally 3) the generation of the WebSocket message evaluated in less than 10 ms. 2. Communication latency between OBU to backend (variable time, depending on communication channel used) 3. Time to store probe data into the database (< 20 ms)
eCo-FEV Backend Message process rate	Average time interval of probe management database update	≤ 60 ± 10 s	< 20 ms Probe messages are stored in the database immediately after received by the backend. Thus, this interval is bounded by the process time needed to store probe data into the database.

Route search latency	Average time interval between route search request time stamp and KML time stamp	≤ 10 s	The route calculation time depends on a number of factors: route length, number of charging stations needed up to the destination and server capabilities in terms of scalability and performance of CPU/memory. Since the backend implementation is still a prototype, no scalability or CPU/memory requirements have been define. Therefore, this metric focuses only on the performance trend when varying the two first factors, namely, route length and number of charging stations used**.** The figure 5.1 shows the result of the analysis.
Time to start the new route guidance	Average time interval between the get route request and the navigation guidance start	≤ 10 s	This metric represents the time interval between the HMI action of the request of eCo-FEV aided navigation and the first navigation indications issued to the driver. This interval englobes the route search latency (described in previous metric above), preparation of the navigation indications and the update of the map on the HMI device. During the tests we observed the metric varied between 2 seconds and 8 seconds. Estimation of the internal OBU latencies confirmed that this time interval depends essentiality on the complexity of planned route (c.f. the description of the metric above) and on the quality of the network connection. These internal latencies were: 1) the WebSocket processing time of the route message sent by the OBU and evaluated in less than 2 ms plus 2) the communication time between the WebSocket manager service and the HMI process evaluated in less than 10 ms, 3) the KML extraction time evaluated in less than 2 ms and finally the HMI map update and the navigation indication preparation varied between 100 and 200 ms.

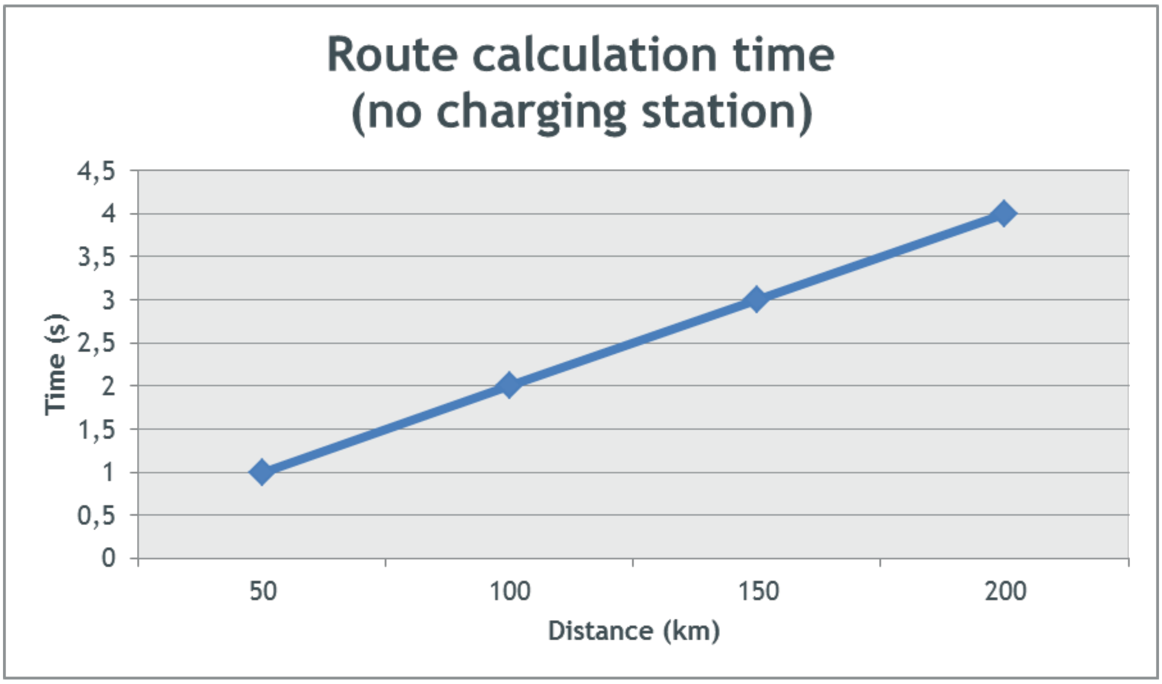
Time to consider the rerouting information	Average time interval between the route update notification and the new navigation guidance	≤ 10 s	This interval is equivalent to two times the average time interval between the get route request and the navigation guidance start (described in previous metric above). Upon an event that triggers a notification, a new route is calculated and suggested to the user. If the user accepts the new route, a final check (route calculation) is performed to ensure that the user receives to most up-to-date route according to the latest parameters regarding traffic, charging station availability, etc. This is reasoned by the fact that the user might take some time before accepting the new suggested route.
eCo-FEV Backend Application process validity	Percentage of failure responses [2] to application requests	≤ 10%	<1% if information about charging spots are available.
IP connectivity latency through the RSU	Time for an OBU to get a usable IP address assigned by the RSU for Internet connectivity of the OBU	≤ 5 s	This time is divided in Link-layer times and DHCP time plus Mobile IP updating time (this latter only if not using NAT bypassing). In practice, the link-layer time and DHCP times dominate all others. These two times are variable, depending on the on-going traffic (if no traffic, link-layer decision is faster) and DHCP state at server (depending on the arrival time compared to the allocated lease, the DHCP configuration time may be longer or shorter). In the eCo-FEV demonstration this time through RSU is shown to vary between 0.5 seconds and 10 seconds.

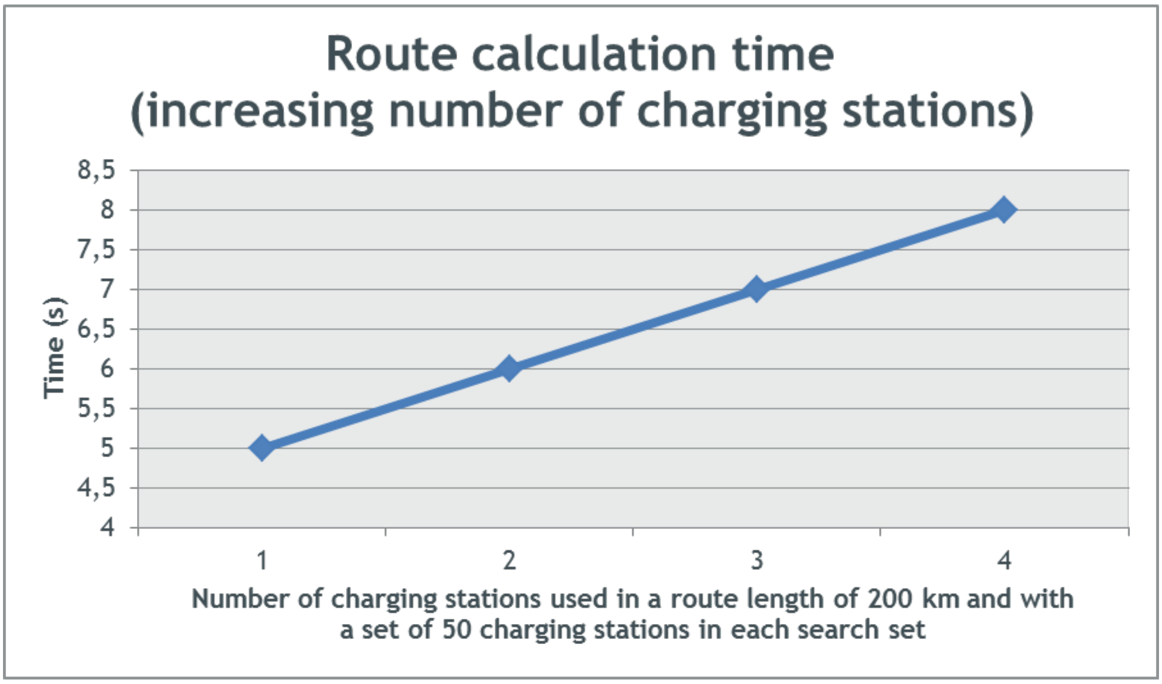
[2] An application failure is defined as an event of application request processing error. Such failure may be caused by multiple reasons, e.g. communication failure, required data for processing being unavailable, algorithm bug, etc. However, if the eCo-FEV Backend is able to process the application request but cannot provide a positive reply, i.e. cannot fulfill the request, for example, due to all charging stations being occupied; then this event is not counted as application failure because such operational behaviour is out of control of the eCo-FEV system.

Time to find and book an available charging station	Average time to locate and book an available charging station spot for an eCo-FEV user	≤ 60 sec.	<1 sec per user request In the backend, the search of a charging station is done automatically during the route calculation whenever the battery energy available is not sufficient for the EV to reach the destination or when a charging station is located near an exchange point of transportation (e.g., Park and Ride near a bus stop). Alternately, a charging station search can be manually requested by the user in the nearby region. In both cases, the time to select a charging station depends on the number of charging stations available in the search area. The selection is done based on factors such as distance to final destination and waiting time in the charging station. The selection time is in the order of milliseconds and increase linearly as the number of charging stations increase in the search set.
Time to authenticate for charging	Average time that elapses from the initiation of charging request to the reception of authentication (before the start of energy flow).	≤ 5 sec.	• The average time for inductive charging is 2,5 to 3,5 seconds including the ANPR detection • For the conductive charging over a narrow GPRS connection the average time is 4 - 6 seconds (Note this is not crucial for the conductive charging use case).
Accuracy and timeliness of charging status accessibility information	Success (correctness) ratio of available/busy status indicators for EVSEs provided by eCo-FEV to the user (ability to cope with accessibility changes)	≥ 95%	99.9% The availability information is up-to-date and always pushed to the backend when a change occurs to any charging station.
Efficiency of eCo-FEV trip / driving assistance	Ability of eCo-FEV to reflect external factors, traffic and charging facility availability conditions in proper planning of requested trip	Positive user ratings (≥ 80%)	N/A No test on user experience has been performed

Table 5.1. Initial list of performance metrics for eCo-FEV service quality assessment

Figure 5.1. Route calculation time





5.2 Backend Evaluation

The evaluation dataset definition is strongly linked to the evaluation criteria and performance indicators as defined in D400.1. The validation and estimation of the eCo-FEV Backend and its functions is mainly related to the following aspects.

- *Performance aspect*: to validate the performance of the eCo-FEV backend to satisfy the application requirements and user needs, according to WP200. The main performance indicators of the eCo-FEV backend is related to the capability of the system to properly collect, process data from multiple data sources and proceed the user request in a timely manner.
- *Communication aspect*: to validate that the information exchanges between eCo-FEV backend and other eCo-FEV sub systems (OBU, RSU, charging infrastructure) and with external infrastructure systems (traffic operator) are properly executed. In addition, the communication between the sub components of the eCo-FEV system is also validated.

It should be noted that the above mentioned performance of the eCo-FEV Backend may be impacted by the external infrastructure systems and cannot be compensated by the eCo-FEV Backend system alone. For example, the data collection performance is highly dependent on the data source, while the data processing performance may be impacted by the availability and freshness of the data being provided by the infrastructure systems. Furthermore, due to the limited number of vehicles and charging infrastructures being available in eCo-FEV testing, only part of overall set of data collected during the test has numerical validity. For this reason further technical validation activities might be foreseen via a pilot project.

5.3 ICT services validation

In order to address some of the key performance indicators as listed above (§5.1, Executive Summary), the EV Dynamic Navigation use case developed within eCo-FEV has been used. This use case allows to evaluate several functionalities since the logic of the use case make use of different sub-use cases as described in previous deliverable. For this reason the following analysis consider the subsequent functionalities.

- Trip assistance
- Notification function
- User request processing

Due to the limited number of FEVs and charging infrastructure systems available in the project for testing, for some of the metrics it was difficult to evaluate the quality: e.g. route search functionalities, for which a pilot activity would allow to evaluate in details further parameters and provide statistically relevant results. For this reason, the conducted evaluation followed a qualitative analyses rather than statistical one. The tests have been performed both in laboratory and on the field.

5.3.1 Analysis and Results

Given the objective of the eCo-FEV project, the main performance indicators of the EV dynamic navigation function are defined as following.

- *Reachability* – the eCo-FEV backend should assist users to reach the final destination with sufficient energy, trying to minimize the travel time.
- *Risk estimation* – the eCo-FEV backend should be able to estimate the impact of an unexpected situation for FEV that may have an impact on the reachability requirements.
- *Rapidness to react on the unexpected situation* – once the unexpected situation is detected, the eCo-FEV backend should be able to react on the situation and propose alternative routes for users.

Based on these performance indicators, the following data have been logged:

User Request

Request_UserID (STRING): User ID of the requesting OBU.

Request_Type (STRING): Type of the user request triggered by OBU, including route search request, C/S search request, C/S availability search request, POI search request, C/S booking/cancellation request, traffic condition search request. Additional user request types may be added during the implementation phase.

Request_Time (DATETIME): Time at which a user request is triggered by user, the information is included in user request message.

Request_Result (STRING): Result of a user request, in case of failure, the nature of failure is logged.

Request_ResponseTime (DATETIME): Time at which a response message is generated by the eCo-FEV Backend.

Note: Such data were mainly used to calculate the response time of the ICT service of the eCo-FEV backend.

Trip assistance

Trip_ID (INTEGER): Identifier for a specific trip, which may be defined at different granularities with driving start and stop times.

FEV_ID (STRING): Vehicle ID of the FEV.

FEV_Route_WayPoint: List of way points calculated by eCo-FEV Backend based on user request, including charging infrastructure position for which FEV is expected to be charged.

FEV_Speed_Profile: Speed of FEV over time, until FEV reaches the destination or the trip is terminated.

FEV_SoC_Profile: SoC level of FEV at a predefined time interval, until FEV reaches the destination or the trip is terminated.

Charging_Record: Set of all charging operations during the trip with location, start and end times as well energy profile for each charging session.

Event_Record: Set of all types of event detected along the calculated route during the trip, e.g. traffic event, weather event, C/S availability notification event, user deviate from the proposed route etc.

Note: Such data, together with data related to notification function were mainly used to calculate the capability of the eCo-FEV backend to inform the FEV about time to consider the rerouting information

Notification Function

Event_Time (DATETIME): Time at which a relevant event is detected.

Event_Type (STRING): Type of event detected within a predefined relevance area around the FEV position, e.g. traffic event, weather event, C/S availability notification event etc.

Event_Validity (DATETIME): Time at which an event is estimated to be terminated (If known).

Event_Notification_Time (DATETIME): Time at which the eCo-FEV backend transmits a relevant event notification to FEV.

Event_Position: Position of the detected event. The event position may be a punctual point, or cover a road segment or an area.

FEV_Position: Position of FEV at the time when the notification is transmitted to FEV.

FEV_SoC (REAL): SoC of FEV at the time when the notification is transmitted to FEV.

FEV_Speed (REAL): Driving speed of FEV at the time when the notification is transmitted to FEV.

FEV_Route: Planned route of FEV at the time when the notification is transmitted to FEV.

Note: Such data, together with data related to trip assistance were mainly used to calculate the capability of the eCo-FEV backend to inform the FEV about time to consider the rerouting information. Additionally, we used this information to understand the time to save new data into database.

EV Dynamic Navigation

Event_Time (DATETIME): Time at which a relevant event is detected.

Event_Type (STRING): Type of event detected within a predefined relevance area around the FEV position, e.g. traffic event, weather event, C/S availability notification event etc.

Event_Validity (DATETIME): Time at which an event is estimated to be terminated (If known).

Event_Notification_Time (DATETIME): Time at which the eCo-FEV backend transmits a relevant event notification to FEV.

Event_Position: Position of the detected event. The event position may be a punctual point, or cover a road segment or an area.

FEV_Position: Position of FEV at the time when the notification is transmitted to FEV.

FEV_SoC (REAL): SoC of FEV at the time when the notification is transmitted to FEV.

FEV_Speed (REAL): Driving speed of FEV at the time when the notification is transmitted to FEV.

FEV_Route: Planned route of FEV at the time when the notification is transmitted to FEV.

During laboratory tests, the overall functionality of the ICT services was tested. Additionally, the *Risk estimation* and *Rapidness to react to unexpected situation* were evaluated over 1 month of tests. It must be noted that events were generated on purpose to evaluate the stability of the system. During these tests, we were also able to assess the potential impact of missing information from charging and traffic infrastructures.

The field tests last for a total of 3 weeks. The tests were used to estimate qualitatively the reachability of the system. Due to the fact that the tests were conducted in a non-naturalistic way, additional piloted tests are necessary to assess statistically the problem.

With above data collected during several sessions of tests, the Key Performance Indicators have been calculated and the following take away have been identified:

Reachability	The system is able to adapt the trip to the situation in order to allow the user to reach destination under the condition that: - Charging spots are distributed in the area where the system is acting - CWD technology is supporting the system in critical situation - The OBU is able to provide regular information about SoC and other parameters connected with the consumption of energy. If above conditions are met, the reachability might reach 99% of the cases. Nevertheless, further study via piloting project with sufficient number of vehicles needs to be taken into account to accurately evaluate such value.
Risk Estimation	The system is able to estimate the impact of an unexpected situation for FEV by estimating the risk of: - SoC profile and anomalies[3] - Traffic situation changes - Weather conditions - Deviation from planned trip During the evaluation the differences between an estimated SoC (during trip planning) and real SoC caused the request of trip planning especially in the initial phase where little data about consumption of electric vehicle was available. This, on the other hand, helped to validate the capability of the eCo-FEV backend to estimate the risk and trigger countermeasures to assure the

[3] In literature, the term SOC is generally used to define the battery state of charge as percentage unit being a state or a ratio of charge. As a matter of fact, our analyses in D400.4 needed to deal with energy variations by monitoring the Level of Charging (LOC) or even a SOC, yet related to accumulated energy in a battery. This last corresponds to the energy stored expressed in kWh and not in %, a value that can be obtained by multiplying the SOC [%] by the battery Capacity [kWh], which is approximately a constant given a certain vehicle. This means that hereafter the SOC is actually a LOC or a kSOC or even an absolute SOC of a specific battery. We excuse ourselves for the confusion that this might arise to the Reader.

	reachability.
Rapidness to react to unexpected situation	The system is able to react rapidly to the event under the condition that FEV is able to provide enough information to the backend. During the evaluation we did not notice impacts of Traffic/Weather infrastructure and C/S Infrastructure since the connectivity is more stable. In any case, in order to avoid excessive burthen on the server running the backend, appropriates parameters should be set to configure the system.

Table 5.2. Variable (dynamic) Navigation key performance indicators

5.4 Communications with other subsystems

The main scope of this evaluation has been to evaluate technically the impact of communication system on the interaction between the eCo-FEV subsystems. We can divide this analysis with respect to the method of communication:

- eCo-FEV backend – FEV interaction: Cellular or G5 (Wi-Fi)
- eCo-FEV backend – all other infrastructures interaction: cabled network

The tests have been performed both in laboratory and on the field.

5.4.1 Analysis and Results

The main factors affecting the interactions between subsystems are defined as following:

- *Latency* – the latency is the time from the source sending a packet to the destination receiving it.
- *Packet loss* – the packet loss is the failure of one or more transmitted packets to arrive at their destination.
- *Network Coverage* – the network coverage is the geographical area, in which a wireless network provider offers cellular service for mobile phone users.

In order to perform this evaluation, the dataset records the communication events either triggered from the eCo-FEV backend or requested to the eCo-FEV backend, in order to enable the evaluation of communication performance.

OBU_PushVRM_Request (DATETIME): Time instances at which the BE receives CoAP requests from OBU. A CoAP request corresponds to the transmission of a VehicleRelationshipMessage.

OBU_VRMSize (INTEGER): Size of VRM messages (CoAP request).

OBU_SessionCreationRequest (DATETIME): Time at which the BE receives a session creation request from an OBU.

OBU_SessionCreationFailure (DATETIME): Time at which the session creation is failed.

OBU_SessionEndRequest (DATETIME): Time at which the BE receives a session end request from an OBU.

OBU_SessionOpen (DATETIME): Time at which a session between BE and OBU is established.

OBU_SessionEnd (DATETIME): Time at which a session between BE and OBU is stopped.

Infra_HTTPRequest (DATETIME): Time at which BE receives an HTTP request from the infrastructure system.

Infra_HTTPResponse (DATETIME): Time at which BE sends an HTTP response.

Infra_IP (STRING): IP address of the infrastructure system.

Infra_HTTP_MessageType (STRING): Type of HTTP message.

Infra_HTTP_MessageSize (STRING): Size of HTTP message.

MessageCount (INT): Number of messages being received by BE per message type.

MessageDecodeCount (INT): Number of messages being correctly decoded per message type.

During laboratory tests, the communication with the different infrastructures was tested. For what concern the charging infrastructure the data have been collected over a period of 3 months. A part of sporadic connectivity issues encountered during the test period, no particular aspect requires comments. Regarding the traffic infrastructure, we tested for a period of 1 month. In both cases, the collection of data continued until the last day of the project since the backend was still up and running and connected with other sub-systems.

The field tests last for a total of 3 weeks. The tests were used to estimate mainly the impact of the communication between vehicle and backend. Due to the fact that the tests were conducted in a non-naturalistic way, and especially localized around the area of the test site we expect that additional piloted tests are necessary to assess statistically the impact.

With above data collected during several sessions of tests, the following results have been identified:

	eCo-FEV backend – FEV	eCo-FEV backend – all other infrastructures
Latency	The communication system does not impact on the performances of the backend since the typical latency of 3G network is in the order of hundreds of millisecond and application requires reaction time less than 10 seconds.	The communication system does not impact on the performances of the backend.
Packet Loss	The communication system might affect the performance of the system in the case a few packets are transmitted from the FEV to the backend. It is suggested to have a mechanism which monitors the packet loss and increase the frequency of VRM packets transmitted from the FEV.	The communication system does not impact on the performances of the backend.
Network Coverage	Lack of network coverage might affect hardly the performance of the system causing a disruption of the service provided by the eCo-FEV platform. Additionally in the case the network coverage is not continuous, a similar probability of disruption is observed with the difference that the system is able to communicate missing information when connectivity is again active.	Not applicable

Table 5.3. Backend interactions capability

5.5 Charging Infrastructure evaluation

The Performance of the charging infrastructure has an influence on the overall performance of the eCo-FEV system. Thus it is important to make some assertions on the performance to the system regarding the correctness and the responsiveness.

Like many distributed systems the actual setup – especially the type of the used network access technology - plays an enormous role in the performance of the system. After the validation ensured that the interfaces work as expected, the performance evaluation gives information about the quality and usability of the system. As described in deliverable D400.1 and D400.2 the charging infrastructure subsystem performance evaluation examines its functionalities while considering the pre-defined performance indicators which give an assertion about the quality and usability of the system and its services. This is done based on the pre-defined evaluation datasets. These dataset gather the relevant evaluation parameters for the given functionalities.

Among other parameters, the datasets retain timestamp information. Given the nature of the charging infrastructure as a distributed system, the data had to be gathered on topologically distant points. In order to avoid clock shifts on the different machines and microcontrollers (resulting in faulty measurements), it was important to have an adequate time synchronization among all the participating nodes. This synchronization was done using the Network Time Protocol (NTP) IETF RFC 958. Each CSCU runs the NTP daemon, as well as the EVSE-Operator’s RADIUS server, OCPP Central System and web-service virtual machine. This way the timestamp is accurate on the machine that generated it, and stays accurate after transmission even if the network delay or jitter varies. On the commercial EVSE, the implemented OCPP protocol in its version 1.5 foresees including timestamp in the XML messages. The accuracy of these timestamps is only guaranteed in case the microcontroller running at the EVSE also uses a synchronization mechanism. Upon request, the manufacturer asserted that the EVSE’s microcontroller runs NTP, yet it is not possible to control this information. Thus for the following analysis it is assumed that the conductive charging EVSE uses time synchronization.

The performance indicators as defined in D400.2 that are explicitly influenced by the performance of the charging infrastructure are the following:

1. **Time to find and book an available charging station**: Average time to locate and book an available charging station spot for an eCo-FEV user
2. **Time to authenticate for charging**: Average time that elapses from the initiation of charging request to the reception of authentication (before the start of energy flow).

3. **Accuracy and timeliness of charging status accessibility information**: Success (correctness) ratio of available/busy status indicators for EVSEs provided by eCo-FEV to the user (ability to cope with accessibility changes

The first indicator relates to the booking functionality, the second explicitly relates the Authentication and Authorization functionality, and the third performance indicator relates to the monitoring functionality. In the following sections the performance of each one of these functionalities will be analysed.

5.5.1 Performance of the Booking functionality

The time needed to find and Book an available Charging Station depends on the functionalities of several subsystems, but also on the Technologies used to provide these services. The Charging infrastructure contribution to fulfil this service is twofold: the monitoring functionality (which will be discussed in later section), and the booking functionality. The latter one for its part depends on the charging technology for which the booking has to be done. As mentioned in the deliverable D300.5 the information flow of the booking functionality differs between the conductive charging and the inductive charging. For inductive charging, the booking information is propagated to the correspondent CSCU from the eCo-FEV Back end through the EVSE-Operator. For conductive charging this booking information is stored at the EVSE-Operator, who controls the access to the conductive charging facilities. In that case the booking is relayed through the EVSE-Operator. These differences not only influence the monitoring functionality but also have influences on the Authentication and Authorization functionalities. Since for inductive charging, the user information is already stored at the road side (CSCU), the authentication is then much faster (given the presence of a previous booking), because the CSCU – EVSE Operator communication is the done in advance. This comes at the cost that the booking information needs to be propagated to the correspondent CSCU adding the CSCU – EVSE Operator interface's performance cost. On the other hand, for conductive charging booking they are done fast, yet do not speed up the Authentication functionality.

The evaluation dataset for the booking functionality of the charging infrastructure subsystem as defined in D400.2 is recalled below:

- **CI_BOOK_Req_TS (DATETIME):** Then timestamp when the EVSE-Operator receives a booking request from the eCo-FEV Back End, captured at the EVSE-Operator
- **CI_BOOK_EVID (STRING):** The ID of the EV for whom the booking is initiated. This could also be the EVSE Contract ID. This information is also captured by the EVSE-Operator.
- **CI_BOOK_ID (STRING)**: The Unique Identifier of the Booking as defined in D200.3, Generated at the EVSE-Operator.

- **CI_BOOK_CSCU_Req_TS (DATETIME):** The timestamp when the CSCU receives the booking execution request. This implies that the booking is possible, i.e. the Charging spot is free and the Contract_ID / EVID is valid.
- **CI_BOOK_Rsp_TS (DATETIME):** The timestamp when the EVSE-Operator replies the eCo-FEV Back End with a Booking response according the D200.3

From this dataset we can calculate the difference between the CI_BOOK_Rsp_TS and CI_BOOK_Req_TS which is the performance of the booking functionality. This is influenced by three factors:

1. **EVSE Operator Processing delay**: occurs at the EVSE Operator to find the “right” Charging station and execute the booking.
2. **Communication delay**: the communication delay between CSCU and EVSE Operator
3. **CSCU Processing delay**: occurring at the CSCU to execute the booking

At the EVSE Operator the charging station information is stored in the RAM making the system extremely responsive. This reduces the processing delay on the EVSE Operator to less than 1 millisecond. This result has been confirmed by the lab-tests (20 runs), as well as by the data logged into the evaluation database (94 reservation requests). The lab tests were done in a short time period (2 days), while data from normal operation has been gathered over the course of seven Months. The Communication delay depends on the setup of the CSCU’s uplink connection. At the Test-site in Susa a broadband connection is available. At the Test site in Grenoble the uplink is over a mobile 3G connection, with potentially higher delays. The Processing delay measured at the CSCU is less than one millisecond.

As for the performance evaluation, lab tests have been conducted where the CSCU and the EVSE Operator are in the same IP subnet (without the communication delay, which differs between different setups). The overall performance is defined by the time between CI_BOOK_Rsp_TS and CI_BOOK_Req_TS. Note that the communication delay would change the values for inductive charging depending on the latency on the EVSE Operator – CSCU link. During the tests on the Susa test site had an average of 400 ms.

The following table summarize the evaluation results of the booking functionality:

	Overall performance
Conductive Charging	< 1 ms
Inductive Charging	7-14 ms (+ link latency = 400 ms)

Table 5.4. Booking evaluation results

5.5.2 Performance of authentication and authorisation functionality

According to the requirements set to the authentication and authorization functionality by the performance indicators as defined in the deliverable D400.2, the authentication time need to be less than five seconds. This requirement is highly relevant for the Charge While Driving use case, since the time is a scarce resource. For the conductive charging the authentication time has an influence on the perceptible service quality. Due to the differences in the implementation between the different charging technologies as described by the architecture of the charging infrastructure in deliverable D300.5, the measurement of the authentication time is different on the two solutions. Although the deliverable D400.2 defines the dataset for conducting the measurement as follows:

- **CI_AUTH_INIT_TS** (DATETIME): The timestamp when the EV or the EV-User (depending on the final implementation) triggers the Authentication process. This information is captured at the CSCU (when possible).
- **CI_AUTH_CID** (STRING): The contract ID of the EV or the EV-user, who is trying to charge at the EVSE. This information is also captured at the CSCU. (UNIQUE)
- **CI_AUTHENTICATE_Req_TS** (DATETIME): The timestamp when the EVSE-Operator receives the Authentication request from the CSCU.
- **CI_AUTHENTICATE_Rsp_TS** (DATETIME): The timestamp when the CSCU receives the authentication response from the EVSE Operator.
- **CI_AAA_PN** (STRING): the Plate-number corresponding the EV or EV-user. (UNIQUE)
- **CI_ANPR_EVENT_TS** (DATETIME): The timestamp when the ANPR Camera signals the Arrival of the EV with the expected Plate-number to the CSCU.
- **CI_AUTHORIZE_TS** (DATETIME): The timestamp when the CSCU sends the activation signal to the power electronics to start the charging.
- **CI_AAA_SESSION_ID** (STRING): the session ID for the Charging session. (UNIQUE)

For the inductive charging, the authentication time is measured on the CSCU. The tests results are partly based on lab-tests (almost 40 runs done on three different days during a period of 2 months), and partly on the data logged into the evaluation database during the normal operation (60 runs, running over a period of four weeks). The authentication has three phases:

- **Phase-1**: RADIUS authentication between CSCU and EVSE-Operator is equal to CI_AUTHENTICATE_Rsp_TS and CI_AUTH_INIT_TS. This is again dependent on the network setup and the CSCU internet access technology. This phase contain the costs for the CSCU – EVSE Operator link and the cost for the RADIUS authentication.
- **Phase-2**: Elapsed time for the ANPR camera to detect the plate number of the EV. This depends on the speed of the car and on the used ANPR camera. During the test in Susa, it has been estimated to 3 seconds.
- **Phase-3**: ANPR detection and sending the trigger to the power Electronics, is equal to the difference between CI_AUTHORIZE_TS and CI_ANPR_EVENT_TS

For the conductive charging solution, calculation the authentication time relies on the OCPP protocol. This calculation is based on lab-tests done at TUB and Schneider Electric labs (60 runs, done on five different days in a period of four months). The results were also confirmed by the data gathered in the evaluation database during the normal operation on the French test-site (50 runs, done in a period of five weeks). Since the CSCU for the conductive charging solution is a closed solution we can rely on the measurement at the EVSSE Operator. Yet there is the possibility of using the timestamp present in some of the OCPP version 1.5 requests (unfortunately the authorize message does not contain a timestamp) like the start-transaction message. Thus the overall costs would be the sum of the three phases:

- **Phase-1**: OCPP authentication request link cost between CSCU and EVSE-Operator, and is equal to the OCPP timestamp and the timestamp when this request arrives at the EVSE Operator.
- **Phase-2**: In this phase the EVSE Operator consults the RADIUS database and the booking information related to the charging station.
- **Phase-3**: this phase is again influenced by the network setup and represents the cost for the OCPP authentication response to arrive to the CSCU. Since the access to the CSCU for the conductive is not possible, the cost of this phase is assumed to be the same as the costs of Phase 1.

On the test-site, the CSCU is connected to the EVSE Operator over a slow GPRS connection that has a high latency. The following table summarizes the evaluation results for the authentication and authorization functionality:

	Phase-1	Phase-2	Phase-3	Overall performance
Conductive Charging	2 - 3 seconds (given a GPRS connection)	< 1 ms	2 - 3 seconds (given a GPRS connection)	4-6 seconds (given a GPRS connection)
Inductive Charging	4 -15 ms + (link latency = 400 ms)	2-3 seconds (given 25-36 Km/h EV speed)	< 1 ms	2,5-3,5 seconds

Table 5.5. AAA evaluation results

5.5.3 Performance of the monitoring functionality

The Monitoring mechanisms in the charging infrastructure differ according to the technical aspects of the different charging technologies. As described above in the architecture of the implemented subsystem, the conductive charging is a commercial solution that uses the OCPP protocol. The Inductive charging, that was completely developed in eCo-FEV, uses SNMP protocol. For the OCPP protocol, the Charging Station (CSCU) autonomously sends the status notification to the EVSE-Operator. There is no possibility to query the status of the charging station by the EVSE Operator. This is why the EVSE-Operator need to keep track of the messages received for each charging station. In case no messages are received, the EVSE Operator assumes that the last status is still valid. This is referred to as push mechanism-

On the other hand, the SNMP protocol used for the inductive charging solution allows not only push mechanism is possible but also pull mechanism is possible. This means that for certain event (mostly for severe events) the CSCU is able to send an SNMP trap to the EVSE Operator. Furthermore SNMP allows pull mechanism, which mean that the EVSE Operator could query the status of each CSCU at any time. What event change should be sent as a trap can be configured on the CSCU. The EVSE Operator can configure the frequency at which the status of the CSCU is pulled. This depends on the importance of the event and on its volatility.

The evaluation dataset (deliverable D400.2) for monitoring defines to measurement points for evaluating the performance of the monitoring functionality:

- **CI_STATE_CHANGE_TS** (DATETIME): timestamp when the CSCU receives a state change event (Error, non-eCo-FEV charging …).
- **CI_EVSE_PUSH_TS** (DATETIME): timestamp when the EVSE-Operator pushes the state change to the eCo-FEV Back End.

The difference between these two timestamp is considered to be the overall time cost as the performance of the monitoring functionality. We differentiate between three cases:

- Case-1 conductive charging: where the overall time cost is calculated using the timestamp contained in the OCPP message called status notification, and the timestamp where the EVSE-Operator calls the push method to the eCo-FEV Back End. The time cost is the sum of the CSCU – EVSE Operator link cost and the processing cost.
- Case-2 inductive charging – prioritized events: the overall time cost is the link cost between CSCU and EVSE Operator added to the processing cost at the EVSE Operator.
- Case-3 inductive charging – normal events: in the worst case, the overall time cost is the sum of the pulling period, the round trip time of the CSCU - EVSE Operator link, and the processing delay at the EVSE Operator.

The results of the performance evaluation differ from case to case. While for case 2 only lab-test data (20 runs) has been used since no major errors occurred during the normal operation. For the normal operation of the inductive charging and conductive charging (cases 1, and 3) the results are based on lab-tests as well as on the data gathered in the evaluation database during the normal operation. The following Table 5.6 summarises the results of the performance evaluation for the monitoring functionality.

	CSCU – to – EVSE Operator link cost	Pulling period	EVSE Operator Processing delay	Overall performance
Conductive Charging	2 - 3 seconds (given a GPRS connection)	-	< 1 ms	2 - 3 seconds (given a GPRS connection)
Inductive Charging prioritized Events	(link latency = 200 ms)	-	< 1 ms	< 210 ms
Inductive Charging Normal Events	(link latency = 400 ms)	2 seconds	< 1 ms	< 2,5 seconds

Table 5.6. Monitoring evaluation results

6 Technical evaluation in France

The technical evaluation performed in France was focused on two different main topics: the technology adopted for communication and the communication functionality for services.

Communication Technology evaluation

To test the communication technology, a total of 14 days have been spent on the test site, using a total of approximately 10 vehicles. Each itinerary (urban and inter-urban) has been performed approximately 30 times. During this time, the total number of test kilometres is approximately 720.

6.1.1 Itinerary profiles

Validation is performed through trials of software prototypes while driving. They are installed in vehicles that are driven at the test site. Each vehicle is equipped with OBUs and AUs. The OBUs have been used in an initial phase to test the coverage of radio signals. Each OBU is equipped with 4G and G5 antennas as well as GPS.

The 4G (4th Generation, LTE – Long-Term Evolution) radio deployment is provided by the cellular network operator Orange at the test site. This includes IPv4 and test IPv6 connectivity. The 802.11p coverage is provided by a Road-Side Unit (RSU) installed by the project, which also includes IPv4 and IPv6. The test area is depicted in the Figure 6.1

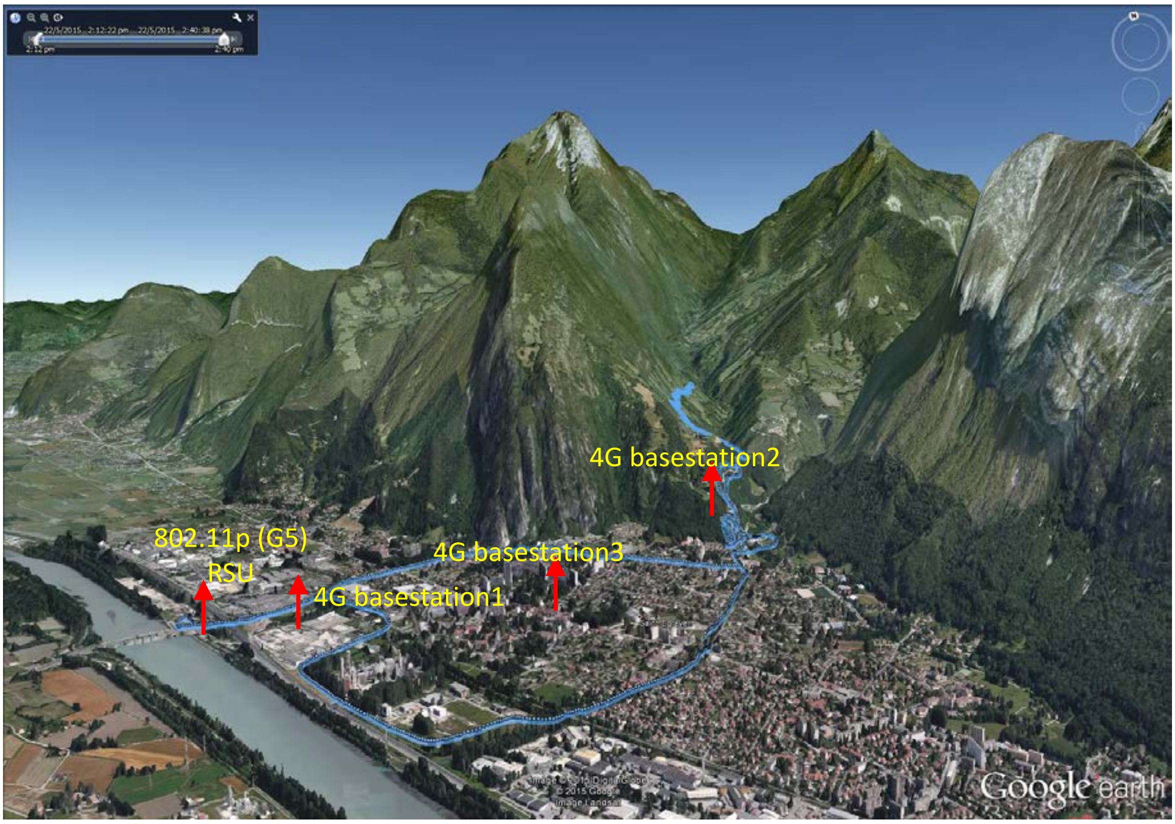


Figure 6.1. Base stations and Road-Side Unit of the itinerary (Grenoble)

In this figure one can see an accentuated three-dimensional representation of the test area. In the lower left corner is situated the P&R parking area. In that area a Road-Side Unit (RSU) is situated. That RSU provides G5 coverage on a radius of approximately 100 meter. This radius varies depending on the signal strength. The 4G deployment is provided by three base stations (basestation1, basestation2 and basestation3) which are situated at the beginning of the itinerary and near the middle of it. The general itinerary is depicted in blue.

There are two types of itinerary: urban itinerary and inter-urban itinerary.

The urban itinerary is performed mainly inside a city, and it is well known to be adapted to the use of electrical vehicles. The inter-urban itinerary is more challenging: it proves the possibility to use an electrical vehicle even outside the city, in areas of high elevation.

In the figure below, the urban itinerary is depicted on the left side and the inter-urban itinerary is on the right side, as 3D images above and as 2D profiles below.

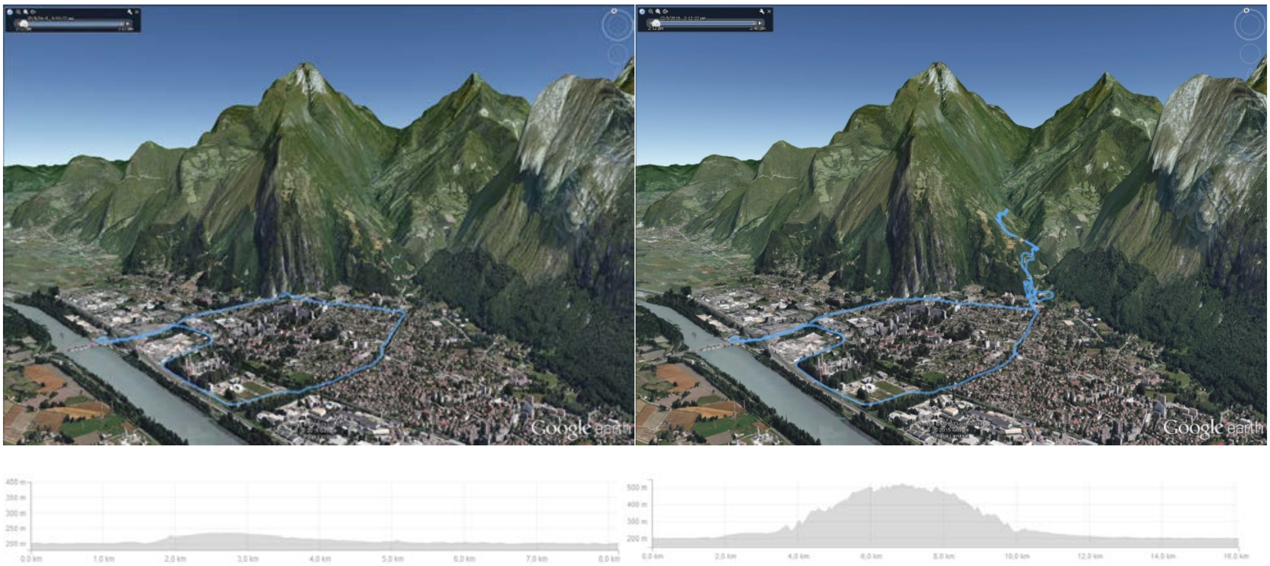


Figure 2: Urban vs Inter-urban Itinerary

The two itineraries have been executed several times. One example of collected data characterizing the two itineraries is listed in the following table:

	Urban itinerary	Inter-urban itinerary
Distance recorded (km); (fixed)	8.1	16.0
Effective driving time recorded (mm:ss); (depends extensively on traffic load, traffic lights, incidents, peak traffic hours)	19:16	28:06
Max difference in height recorded (m)	37	501
Mean estimated proportional energy (W); (depends extensively on vehicle weight, wind conditions)	179	275
Mean speed recorded (km/h)	25.3	34.4
Max speed recorded (km/h)	59.4	83.5

6.1.2 Coverage of the 4G technology at the test site

The Figure 6.3 below depicts the 4G radio signal levels along large parts of the itinerary. In theory, the maximum power level emitted by the Base Stations LTE of Orange is 61 dBm.

Figure 6.3. 4G coverage values along itinerary

In the above figure (Figure 6.3), one can see the radio signal values for technology 4G as measured along the inter-urban itinerary. The dark green points represent 100% of signal strength (maximum power levels, corresponding to approximately 50mbit/s bandwidth and 30ms latency), whereas lighter signals vary from 94 and down to 47% (the lowest value).

During these measurements, it has been validated that a link-layer handover was performed: the OBU changed attachment from basestation1 to basestation2.

It is interesting to remark that the farthest point of the itinerary (on the North East of the figure) still benefits of 86% of signal strength, despite its remote situation from basestation2, and despite being hidden (no line-of-sight).

On the inter-urban itinerary a completely uncovered area is present around coordinates 45.248346N 5.696699E. This is on the mountain slopes and 4G the signal levels on it are (-120dBm.) This provokes some of the harshest disconnections from the network.

Figure 4: Situation of non-covered area (no 4G coverage) is in a portion of the route of dense foliage.

6.1.3 Handovers between 4G cells

During a complete travel along the inter-urban itinerary 47 handovers were performed between 15 different Cell-IDs on 4G. This data is obtained by averaging numerous unitary items of the following format:

```
mardi 19 mai 2015, 10:12:14 (UTC+0200)
[/dev/cdc-wdm1] Successfully got cell location info
Intrafrequency LTE Info
        UE In Idle: 'yes'
        PLMN: '208'
        Tracking Area Code: '1474'
        Global Cell ID: '12174084'
        EUTRA Absolute RF Channel Number: '6400'
        Serving Cell ID: '198'
        Cell Reselection Priority: '4'
        S Non Intra Search Threshold: '10'
        Serving Cell Low Threshold: '4'
        S Intra Search Threshold: '62'
        Cell [0]:
                Physical Cell ID: '198'
                RSRQ: '-7,4' dB
                RSRP: '-96,0' dBm
                RSSI: '-71,6' dBm
                Cell Selection RX Level: '30'
Interfrequency LTE Info
        UE In Idle: 'yes'
        Frequency [0]:
                EUTRA Absolute RF Channel Number: '3000'
                Selection RX Level Low Threshold: '0'
                Cell Selection RX Level High Threshold: '16'
                Cell Reselection Priority: '6'
                Cell [0]:
                        Physical Cell ID: '0'
                        RSRQ: '0,0' dB
                        RSRP: '0,0' dBm
                        RSSI: '0,0' dBm
                        Cell Selection RX Level: '0'
LTE Info Neighboring GSM
        UE In Idle: 'yes'
LTE Info Neighboring WCDMA
        UE In Idle: 'yes'
----
```

Figure 5: Unitary measurement of 4G power level

6.1.4 Coverage of the 802.11p technology at the test site

In the figure below we depict the 802.11p radio signal values around the RSU deployed in the P&R area. They are represented as negative dBm values.

Figure 6.6. 802.11p (G5) radio signal levels at the test site

At the P&R area of the test site a Road-Side Unit is deployed on a light pole. This RSU is able to emit with a theoretical power of 25dBm, and uses an omnidirectional antenna qualified as 12dBm. The regulated power level (EIRP) cannot be larger than 33 dBm. The validation measurements around the RSU show values ranging from -102 to -66 dBm. The former (-102dBm) correspond to very low signal level, practically impossible to use to establish IP connections. The radio level near the antenna pole is -66dBm. The radio level measured at centimetre distance is around -20dBm (but this value does not occur in practice since the antenna is on a pole above ground, around 10meter).

6.1.5 Handovers between 4G cell and 802.11p area

The handovers between 4G and 802.11p area are performed 4 times during each itinerary. First, when leaving the P&R (covered in large part by 802.11p) there is one handover from 802.11p to 4G. This handover takes in average 20seconds between the moment of detection of 11p signal loss and the moment of application continuation. Second, when approaching the P&R (end of itinerary), the handover takes in average 5 to 10 seconds between the moment of detection of the 11p signal and the moment of application continuation.

6.1.6 Emulating movement through radio signal level variation

The radio signal mapping at the test site permitted not only to plan a 4G-G5 handover demonstration in best conditions, but also allowed emulation of vehicle movement in laboratory. A signal level trace was performed on site to expose the variation of the 802.11p (G5) levels. Then a transformation of these levels was performed to use as an input to RSU. This RSU is used in the laboratory testing to emulate radio conditions. Using an RSU in laboratory testing is extremely useful for developing software for handover management. The RSUs have capabilities to vary the emitted signal levels. However, it is very difficult to make a correlation between the signal level specified at input of the RSU and the signal level perceived by the OBU passing at a certain distance of it. This difficulty is illustrated in the Figure 6.7.

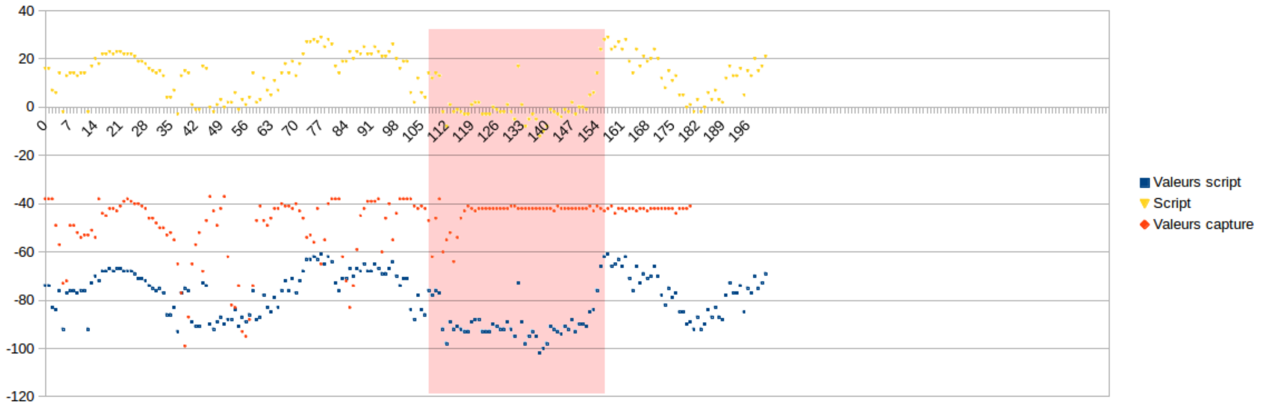


Figure 6.7. Difference between input signal to RSU and signal sensed at OBU

In the above figure there are three curves denoted “Valeurs script” above, “Script” in the middle and “Valeurs capture” at the bottom.

The Y-axis is the signal strength and the X-axis is the time. The signals in the middle (“Valeurs capture”) along the time axis correspond to a particular itinerary of the OBU around the RSU, on the real road. During this capture, the input to the RSU was kept constant at 25dBm.

From these values (“Valeurs capture”) it is necessary to deduce values to be set in a script. This script will be applied to the input of the RSU. The goal is to obtain again at the capture time the same values as during the capture on the road.

However, a trivial set of values (the values put in the “Script” curve at the top) produce values situated at the curve at the bottom of the figure (“Valeurs script”), captured at the OBU. These values do not correspond to the real values (the middle curve) although their variation follows the variation of the real values.

For this reason, it was necessary to further decrease the values set in the script such as to arrive at the same "Valeurs script" as the "Valeur capture". Once the curve "Valeurs script" is perfectly super-imposed over the curve "Valeurs capture" it is considered that a script was built. This script corresponds to the real movement of the vehicle on the road. It can be used to fully simulate it in a laboratory environment.

6.1.7 Human exposure to the electro-magnetic fields for 4G

The 4G deployment at the Grenoble test-site (Saint Egrève) is ensuring the power levels are below the threshold limits decided for France. The maximum allowed power levels for 4G are 61 dBm as of May 2015. A measurement performed by laboratory AEXPERTISE in a house at the test site (32 rue des Bonnais) concludes that the exposure limit values fixed by decree of May 3rd, 2002, are respected. For more details see "Fiche mesure N° 115893" on the site cartoradio.fr, or otherwise the "Rapport d'essai champ électromagnétique in situ, reference TG071403-R, version 1" edited by AEXPERTISE in Marseille, France.

6.2 Communication Services evaluation

The electrical evolution of the conductive charging was not in the scope of the project. The project applied the market available solution compatible with the "EV Ready" standard. All modifications applied by the eCo-FEV project concerned the ICT aspect of the Authentication, Authorization, Accounting (AAA) procedures described in the "Charging Infrastructure evaluation" chapter.

As abovementioned from the FEV point of view the evaluation concerned the communication services between the FEV and eCo-FEV backend and the behaviour of the navigation interface.

The communication services were evaluated in common with the eCo-FEV backend and their validation is described in the "ICT services validation" chapter.

The essential FEV validation part concerned the on board navigation interface and its reaction to the backend solicitations:

- New route charging and navigation start
- Route update (rerouting due to the traffic events) and new guidance start.

In order to perform the evaluation, we recorded all events triggered by the communication between the eCo-FEV backend and the FEV.

Thanks to the data collected during all tests we obtained the following "FEV specific" results:

1. Communication and ICT services:

	eCo-FEV backend – FEV
Network latency	The communication system does not impact on the performances of the navigation interface.
Isolated network packet Loss	The loss of packets may influence the quality of the end-user service. Especially it concerns the VRM (probe) CoAP/UDP messages transmitted from the FEV to the backend. It can be interesting to add the acknowledgement to the VRP messages.
Loss of communication	Loss of communication (due to the lack of network coverage or other reasons) might produce the disruption of the service provided by the eCo-FEV backend. It was demonstrated that the system was able to recover from the various communication issues when connectivity became again active.

2. Navigation interface, reactivity and end user experience:

	eCo-FEV backend – FEV
New route navigation start	The search of the route on the back-end does not impact the time of the guidance start time. This time was always lower than 5 seconds.
Route update, rerouting	Taking into consideration of the new route proposed by the backed does not impact the quality of the navigation guidance; the time without the guidance was always lower than 5 seconds.

Table 6.1. Navigation results in French test site

6.3 Final test

Experimentation on French test site enabled to test successfully advanced ICT eCo-FEV services in real conditions on public domain, while interfacing with different currently operating infrastructures.

From a technical point of view, the delivery of advanced ICT eCo-FEV services based on vehicle connectivity and infrastructures interfacing have been validated.

- The connectivity of the vehicle based on OBU technology has been validated both by using mobile cellular network (3G/4G) in general and by using IEEE802.11.p (G5) on localised site (closed to the park ride where a G5 UBR has been installed). So the connectivity has been technically demonstrated in the current context required for a short term deployment but also for integration into the future cooperative smart road. This connectivity has been validated both on urban and extra-urban travels, taking into account the needs to secure both types of travels.

- The interface with real currently operating infrastructure has been validated:
    - Interfacing with conductive EV charging infrastructure installed in a car park ride was validated, enabling all EV charging operations included AAA process and booking operation. It can be highlighted that the interfacing was validated in real conditions in advanced commercial installation which represents a real case of EV charging infrastructure opened to public.
    - Interfacing with traffic management centre, including both road traffic management centre and public transport management centre, which are currently in operation and supply dynamic advanced qualified traffic information in real time. Dynamic road traffic information enables to secure EV travels. Dynamic public transport information enable eCo-FEV services to propose multimodal mobility solutions.
    - As a remark, interfaces are based as much as possible on European standardised protocols or practices: OCPP1.5 for interfacing with EVSE, DATEXIIv2 for interfacing with road management centre.

The demonstration was done on a use case combining urban and extra urban mobility on the one hand, and combining electro mobility and multimodality on the other hand. EV travel was secured on one of the most critical EV mobility issue : extra-urban travel on a not meshed road network; taking into account traffic events in real time is critical to manage efficiency and comfort of travel, and moreover autonomy of EV battery. EV travel was secured on one of the most common EV mobility issue: urban traffic congestion; a multimodal solution including EV charging booking opportunity and accurate public transport synchronisation has been demonstrated.

Required technical validation was successfully achieved. Demonstration on a relevant use case was successfully done. So a large scale deployment of ICT eCo-FEV services can be considered to support electro-mobility and further sustainable mobility around and in the smart city.

But high scale experimentation with real users could not be implemented because out of scope and means of eCo-FEV project. This last step would enable to investigate the sociological and operational issue of the implementation of eCo-FEV ICT services, and enable to investigate the scale effects for a complete business and societal validation.

7 Technical evaluation in Italy

The technical evaluation in Italy has been focused on the inductive charging evaluation; this activity has been performed by POLITO in the laboratory environment, beside once on the test site in Susa, and some support on FEV functionality has been provided by CRF.

Although in the Italian Test Site all the needed equipment for charging has been integrated and the work done has been certified (Annex 1) it has been preferred to conduct a preliminary and subsequent intensive test activity in laboratory, because of different technological aspects were under investigation and a laboratory environment could easier implement all features.

7.1 Scope

The test on the inductive power transfer system in CWD has had several purposes summarised in the following list:

- Evaluation of the overall efficiency of the IPT CWD system
- Evaluation of the behaviour in misalignment conditions
- Test of the effectiveness of the adopted power electronic structure and individuation of criticisms
- Tests on the shielding system for human being EMF protection.

7.2 Description

The structure depicted in Figure 7.1 has been built in order to test the CWD prototype in indoor condition.

The structure is composed by a fixed part that emulates the ground pavement, and over which three transmitting coils are placed and a movable structure that emulates the vehicle.

The movable structure sustains the receiving structure with the aluminium shield allowing the reproduction of different condition of positioning in three directions.

The system was supplied through the same power electronics structures adopted for the eCo-FEV test site.

The measurement of the magnetic field inductance has been conducted using an isotropic exposure level tester ELT-400 shown in the following.

Figure 7.1 Prototypal structure for the laboratory test of the IPT CWD system

7.3 Results

The laboratory tests have proved the technical feasibility of the charge while driving infrastructure in terms of effectiveness, efficiency, controllability and safety of human beings.

These results are not obvious since the structure of the power electronics differs from the state-of-the-art power electronics available for similar applications.

These laboratory tests of the charge while driving structure have confirmed the capability of the control board to manage the power transfer from the transmitter to the receiver. The magnetic field measurement has confirmed that the designed structure meets the magnetic field mitigation requirements.

The receiving structure placed below the vehicle has been capable of tolerate the mechanical solicitation under normal driving conditions.

Finally the data collected in real conditions have provided useful information regarding possible improvements of the current transmitting and receiving structure, paving the path for wireless power transfer topologies

7.3.1 Evaluation of the overall efficiency of the IPT CWD system

The overall efficiency of the system has been evaluated on the passage over three transmitting coils measuring the efficiency from DC side (AC/DC converter output) to DC side (HF/DC converter output) as depicted in Figure 7.2.

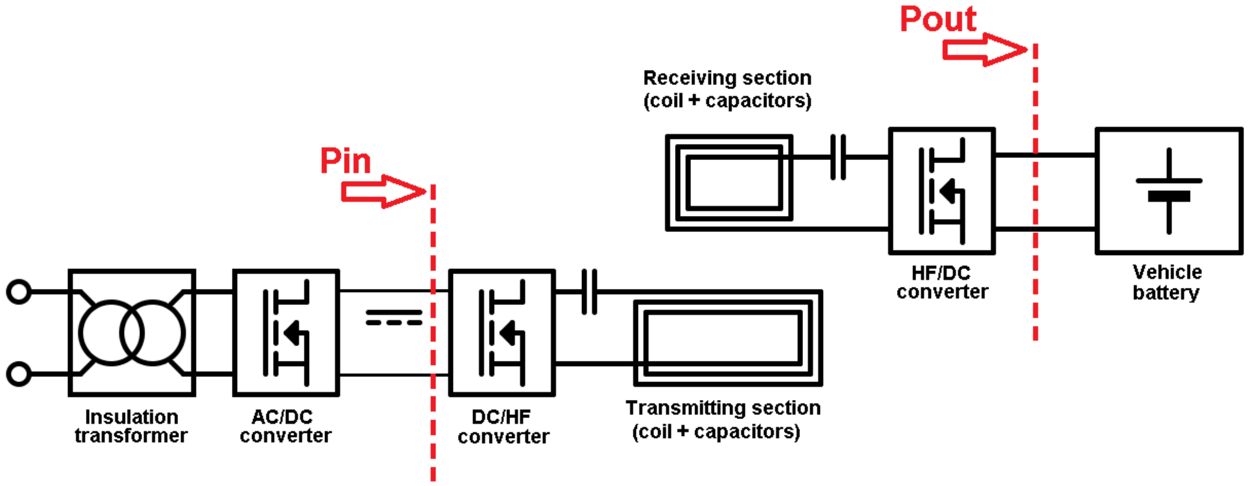


Figure 7.2 Efficiency calculation scheme

The power transfer start is characterised by the shape of the current shown in Figure 7.3 where it is visible a transient overshoot of the typical of the turn on phase of each transmitting coil.

The turn off phase that is commanded when the vehicle is passing over the transmitting coil, is faster than the turn off phase as visible in Figure 7.4.

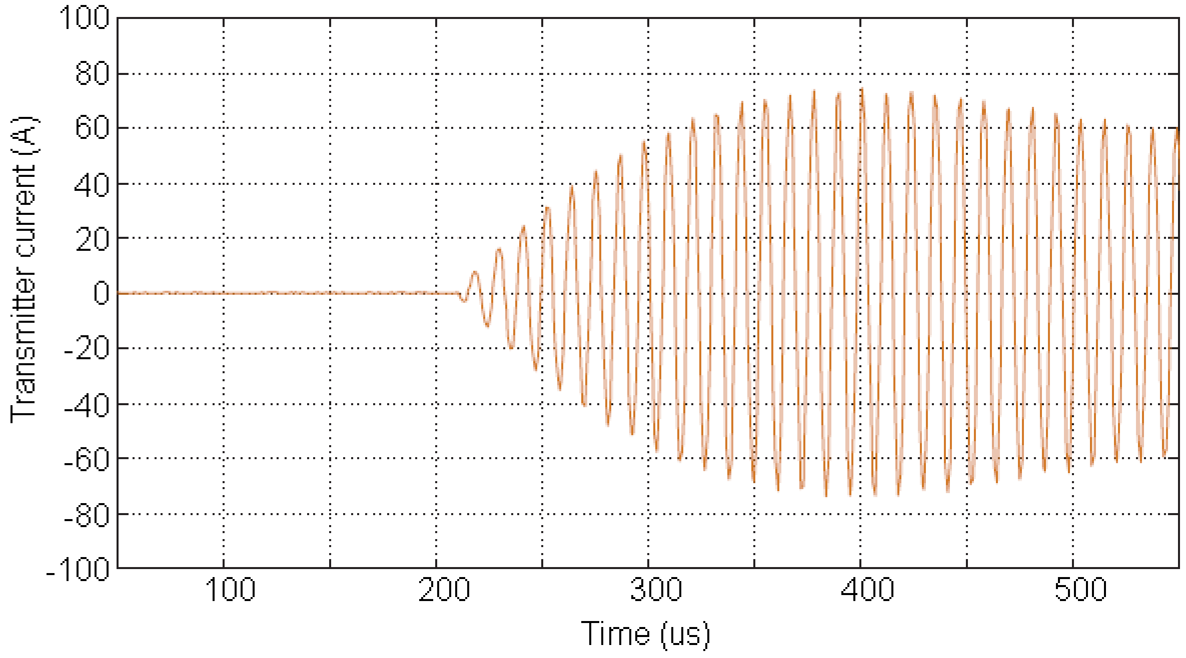


Figure 7.3. Turn ON of a transmitting coil with the presence of the vehicle

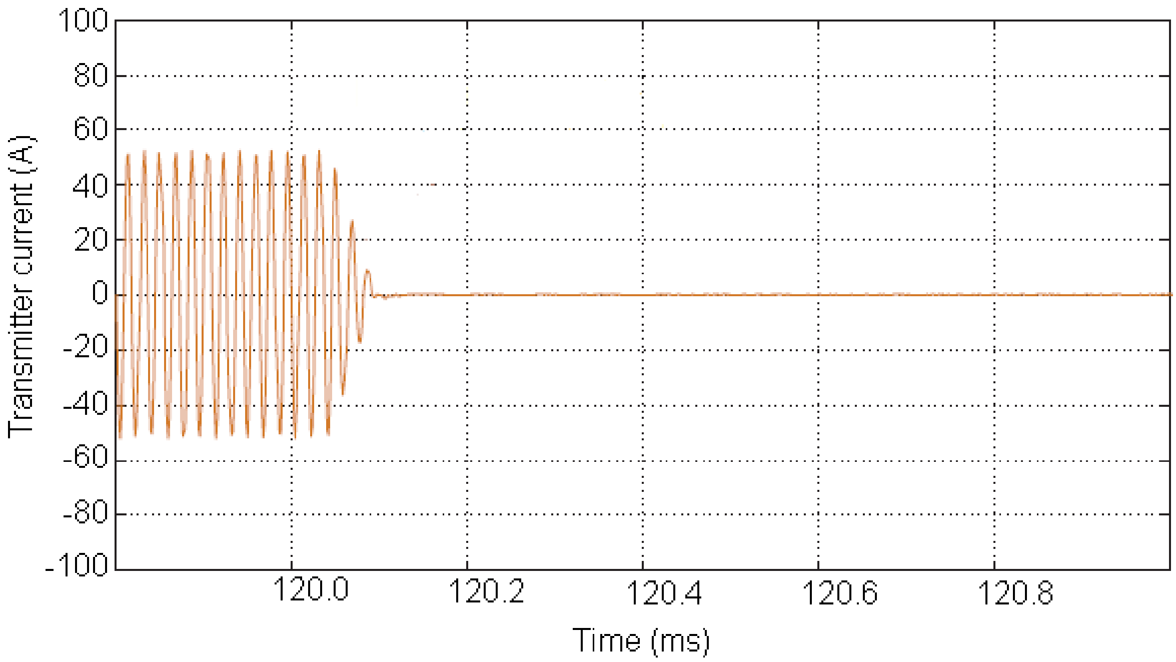


Figure 7.4. Turn OFF of a transmitting coil

The efficiency is evaluated as the mean efficiency measured over the complete charge procedure and is equal to

$$\eta = 84.3\ \%$$

This value is not affected by the speed of the vehicle because the power transfer is related only to the electromagnetic parameters of the transmitting and receiving structures and the speed of the vehicle is negligible respect to the typical time/frequency of the electromagnetic phenomena. This means that the power transfer and the transient phases of turn on and turn off remain independent by the vehicle speed.

Nevertheless, the speed of the vehicle represents a limit in relation with a few main aspects, reported below.

- The power needed by the vehicle increases in a cubic way with the speed so there is a speed limit after that the absorbed power from the battery starts to exceed the power transferred through the IPT CWD system. This means that, the energy balance at the end of the charge process becomes negative.
- This speed depends by the vehicle weight and by the efficiency of the vehicle power train and, in the case of the electric Daily adopted in the eCo-FEV project this limit is of about 50 km/h for the test site coil positioning.
- The control of the DC/HF converter that supplies the transmitting coils becomes difficult if the speed of the vehicle is too high. This difficult is related to the actual architecture of the power electronics that shares an “inverter leg” for two consecutive coils. The passage of the vehicle from one coil to the next one asks for the change of the supplied coil. This means to change the involved legs of the converter maintaining one leg shared.

  While this solution is suitable for low speed and it represents a strong reduction of the costs, it was revealed not so robust if the speed of the vehicle exceeds 30 km/h. After this limit point the fast turn-off/turn on operations causes big oscillations in the power absorbed by the electrical network and it is not so tolerable by the power electronic on vehicle board.

  This is one of the most important results of the experimental tests because it provided important information that will be the basis for future improvement in the design of new power electronic structures with a more robust control.

7.3.2 Evaluation of the behaviour in misalignment conditions

The misalignment changes the power transfer capability and the efficiency of the system. This dependency was tested and the main results are depicted in Figure 7.5and Figure 7.6. The tests were provided in static condition with the receiver centred respect to the middle transmitting coil.

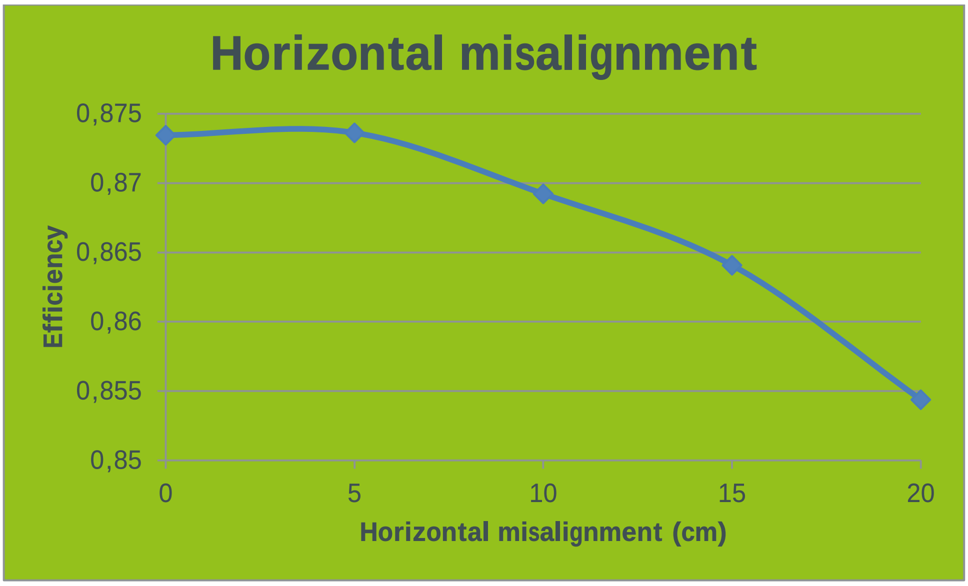


Figure 7.5. Horizontal misalignment test

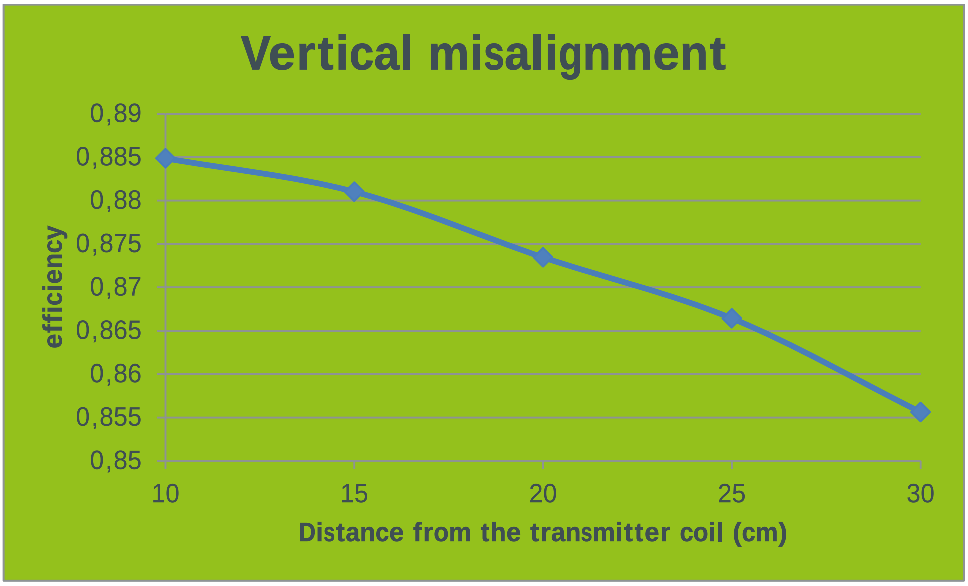


Figure 7.6. Vertical misalignment test

These tests demonstrated the dependency of the power transfer capability and efficiency by the misalignment respect to the nominal position conditions.

The misalignment causes a variation of the magnetic coupling between the receiving and transmitting coils that is the main physical quantity involved in the inductive power transfer.

This aspect is object of present studies that are trying to manage and control this variation adopting an active converter system also on vehicle board instead of the simple diode bridge proposed in the eCo-FEV prototype.

7.3.3 Test of the effectiveness of the adopted power electronic structure and individuation of criticisms

The power electronics that supplies the transmitting coils and the converter on vehicle board were tested to demonstrate their functionality and point out some aspects that need improvement.

In addition to the previous underlined aspects, there are some other good results and opened problem derived from the test that are briefly summarised hereafter.

- The eCo-FEV system implemented a procedure for the identification of the presence of the vehicle only through the power electronic on ground. The proposed technique is well functioning but it is the principal cause of the difference in the efficiency respect to the static charge respect to the one dynamic one.
  Static charge happens in condition of good alignment with the presence of the vehicle that can be confirmed with more accurate methods according to the slow speed of the operation. In this case
  The tested overall efficiency is about 87.3% (as visible in Fig. 5 and 6 at the nominal distance of the two coils of 20 cm).
  In the dynamic charge all these aspects are deputised to the power electronic. As shown in Figure 7, in case of absence of the vehicle a huge current is provided by the power electronic without power transfer. This means that all this current generates losses over the electronic switches and the coil resistance.

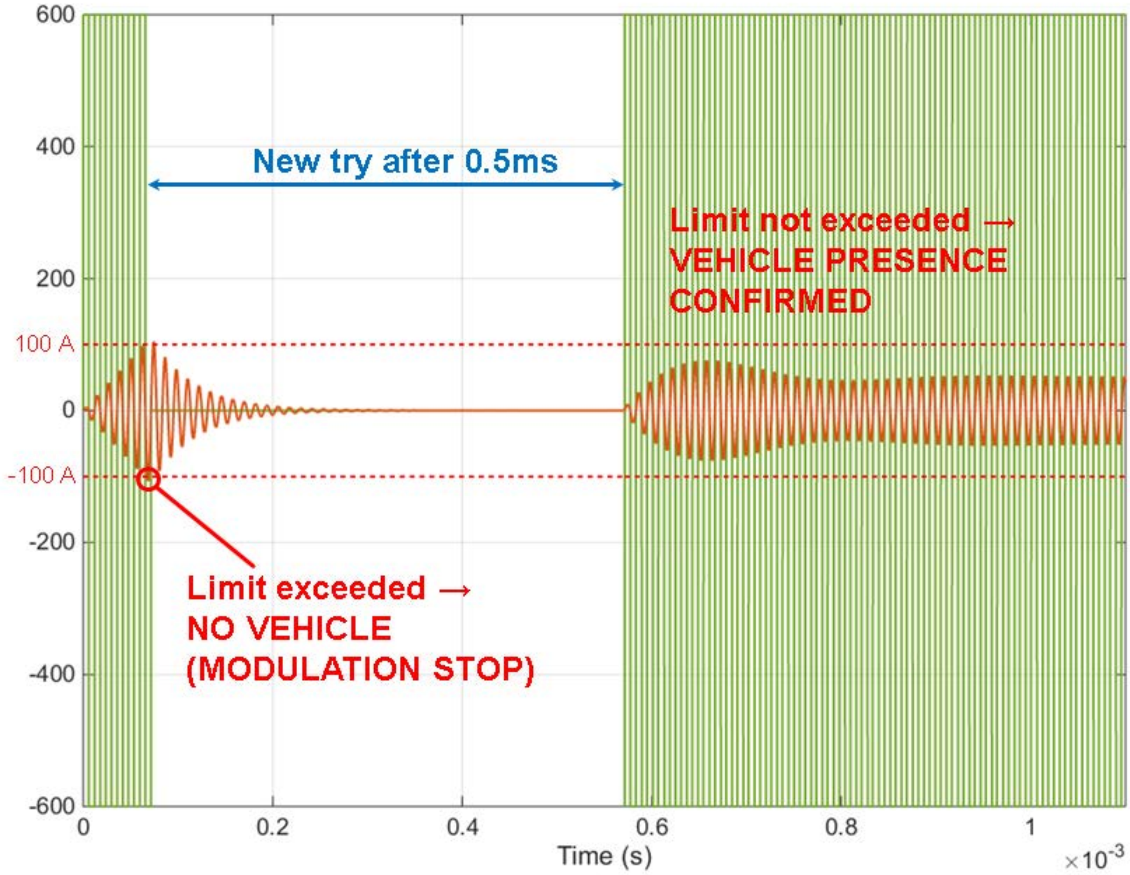


Figure 7.7 Procedure for vehicle identification through the DC/HF converter

This technique can be improved and it will be related with the future design process.

- The proposed structure with a constant voltage on the transmitting side it is confirmed to be a powerful choice. It has confirmed its characteristic of efficiency, good controllability and cheapness.
- More efforts have to be spent in the future to improve the control in the passage of the vehicle to one coil to the closer one. In the present the same technique of individuation of the vehicle is implemented so there is the same problem related to the efficiency of the process.
- The proposed structure that supplies more coils can reveals thermal problems in the case where more vehicles are supplied at the same time. These problem increases if the vehicles stop over the coils. All these aspects are leading towards the adoption of a different power electronic architecture with a single H-bridge is dedicated to each transmitting coil.

7.3.4 Tests on the shielding system for human being EMF protection

A set of measurement has been performed to verify the respect of the limit on the human exposure to the magnetic field provided by the ICNIRP guidelines for limiting exposure to time-varying electric and magnetic fields (1Hz – 100 kHz) in relation with the public.

This measurement pointed out a series of criticisms in the shielding related to the movement of the vehicle of the supplied transmitting coil.

The figure below summarises the different possible conditions of positioning during the charge operation that have been analysed.

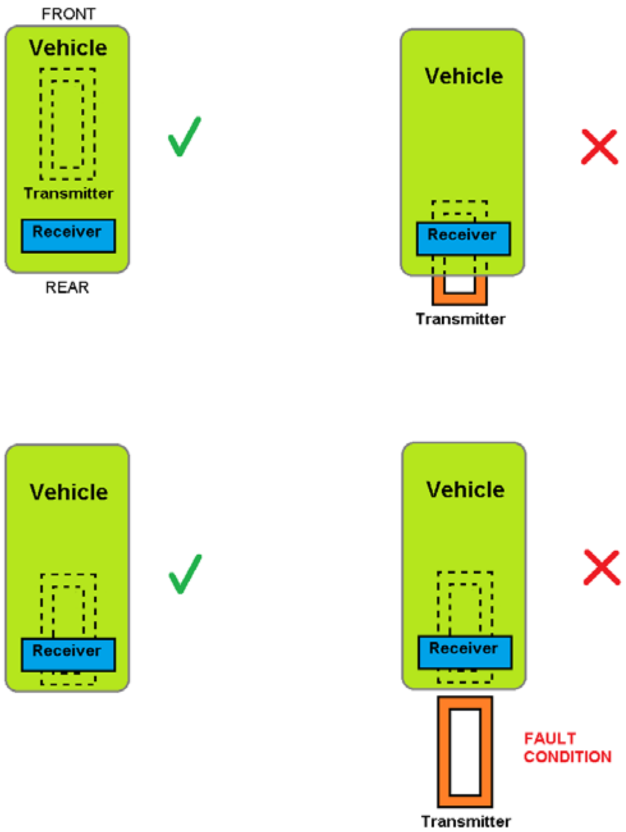


Figure 7.8 Possible positions

The conditions indicated with a red cross are particular condition where a supplied transmitting coil is not totally covered by the vehicle and the adoption of a shielding system is practically impossible. Has to be underlined that one of these cases is a fault condition and the other one where the transmitting coil is only partially covered, is a condition that need for other and more precise evaluations and that could be lead to the adoption of other kind of shielding solution or safety procedure.

It has to be underlined that the red crossed conditions are dictated by the position of the receiver that, in the case of the prototypal version mounted under the adopted vehicle, is not centred respect to the vehicle chassis.

With the receiver placed on the centre, each active transmitting coil is covered by the vehicle. This condition allows having a natural shielding of the magnetic field and a more suitable condition for the management of the protection of humans close to the vehicle.

Figure 7.9 Measurement of the magnetic field induction during the functioning of the system

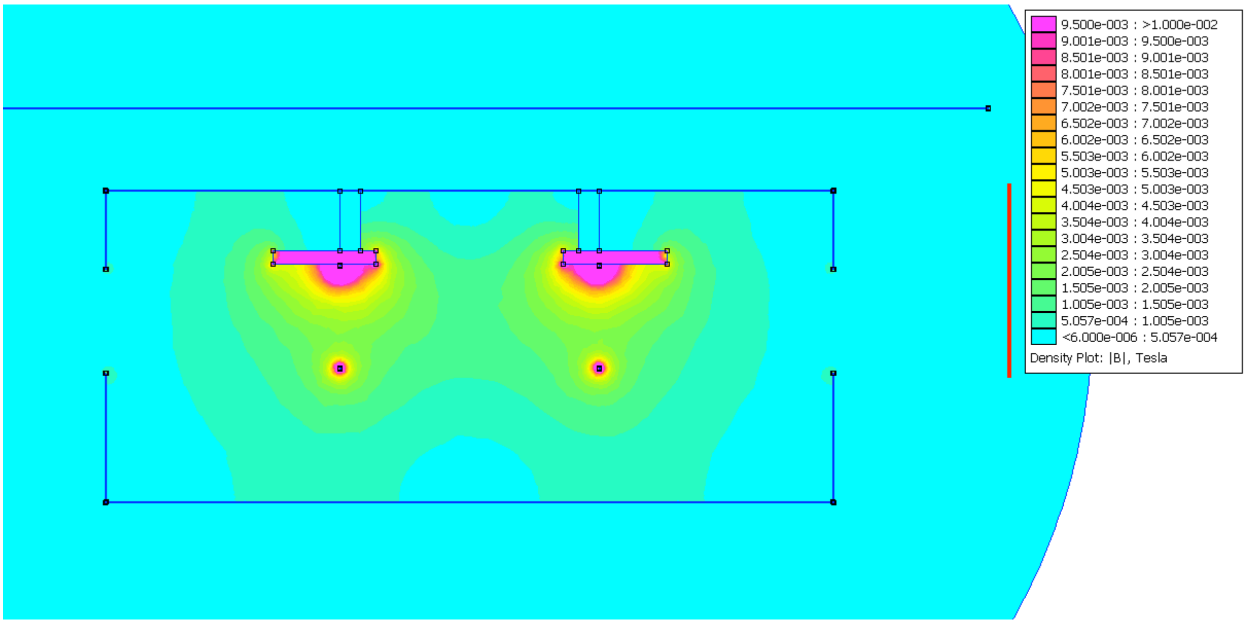


Figure 7.10 2D design results of the induction levels in the schematic shielding structure

The Figure 7.10 shows the 2D design results of the induction levels in the schematic shielding structure. The design process has been based on the human safety factors and some points have been chosen as milestones: no shielding structure from the asphalt to the lower board of the coil. A second design point is the definition of a structure that minimizes the amount of precious material in the whole structure: in detail no ferromagnetic material on ground (lower box). Shown results arrive from of an optimisation process based on a 2D FEA approach.

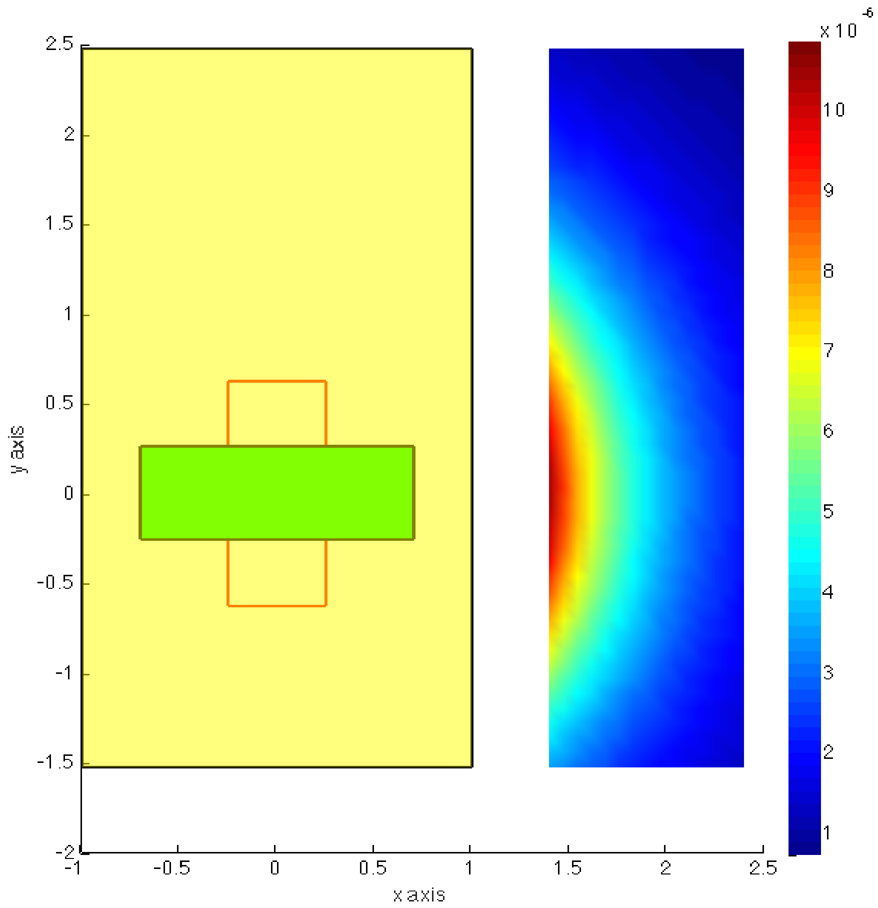


Figure 7.11 3D simulation where the whole structure has been considered including a simplified version of the vehicle chassis (the yellow plane)

The Figure 7.1 is the result of a 3D simulation in which the whole structure has been considered, including a simplified version of the vehicle chassis (the yellow plane).

A colour map representation in Tesla of the induction levels at 10 cm of distance from ground, on the vertical direction, and at 30 cm on the side of the vehicle shows an induction level below ICNIRP2010 limitation for public exposition to continuous field (20micro Tesla). It has to be noted that the CWD solution anyway offers always a pulsating solution because each coil is turned on and off in the worst case at 50% of duty cycle.

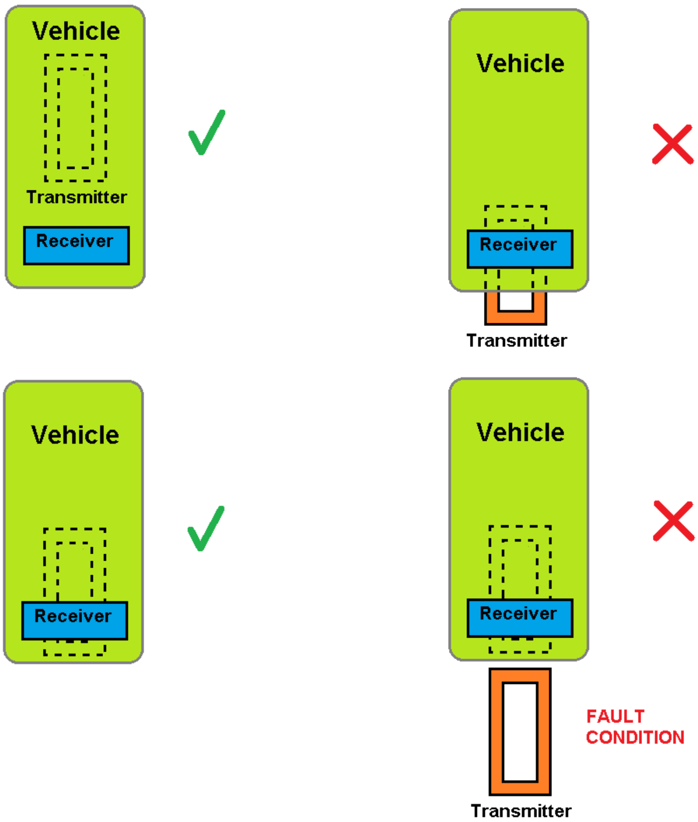


Figure 7.12 Working conditions

These are a picture already shown in which working conditions the ICNIRP limitations have been attended with reference to the previous ones. Final considerations are that the position of the receiving coil on the vehicle is optimal, for the proposed transmission scheme, at the middle of the vehicle in all dimensions (lateral and longitudinal).

8 Conclusion

Important results have been achieved during the technical evaluation of the main components developed within eCo-FEV project.

As well known, as typical of a system engineering approach, in a system we may include software and hardware, operated by people - our experts - who are the integrating and intelligent (ITS) part of the system itself: each component of the system and its behaviour are strictly connected to the other components. However, being some parts of this project in a research phase (CWD), their test is intrinsically carried out within the laboratory and occasionally in the test site (Susa), while being some others (static charging) at an applicative level, their tests consist in the starting test and functional operation of the ITS parts (Grenoble); all the components or subsystems, speaking again with the Systems engineering approach, need an functional testing that would require a more or less extended operation. A similar example may be taken with complex systems as transportation ones (e.g. a metro), where the functional testing implies not rarely 6-months of operation by staff, before being accessible for public transport.

Therefore, the evaluation of the eCo-FEV Backend and its functions considered mainly p*erformance aspects* to satisfy the application requirements and user needs, and c*ommunication aspects* to validate the information exchanges between eCo-FEV backend and other eCo-FEV sub systems, and the impact of communication system on the ICT service provided by the backend. For what concern the application requirements, we evaluated the reachability, the risk estimation and the rapidness to react to unexpected situation. In general the backend has been designed in a way that it can satisfy the key performance requirement of the main ICT service developed within the project: EV Dynamic Navigation. From communication perspective, the evaluation has shown that it is up most important to consider packet loss and network coverage especially for the communication between backend and FEVs. While for packet loss techniques could be deployed to overcome the issues, for the coverage the network availability need to be considered once the service will be deployed.

This deliverable also revisited the charging infrastructure subsystem, its architecture and components. It described the subsystem verification following the methodology described in D400.1. This includes the verification of each component of the subsystem, the inter-component interfaces, and the interfaces to other subsystems. Based on the verified subsystem, this deliverable covers the evaluation of the system according to measured performance parameters as described in D400.2, where also target values for the system performance were set (performance indicators). The evaluation showed that the charging infrastructure satisfies the performance indicators targeted for the subsystem. This evaluation serves as an input for the impact assessment (described in D400.4).

The feasibility of the integration of system components for the inductive charging of electric vehicles in the eCo-FEV infrastructure has been verified. The results of test performed to evaluate the communication capability and the control of the power electronics have been positive. Important indications of possible future improvements in the speed and robustness of the communication network as the adoption of a communication standard more suited for a larger amount of electric vehicles that could use the charge infrastructure. The system is capable to detect possible errors or fault conditions and the power electronics is turned to the safe condition either for the devices and the human beings. The laboratory tests have proved the technical feasibility of the charge while driving infrastructure in terms of effectiveness, efficiency, controllability and safety of human beings.

Finally the data collected in real conditions have provided useful information regarding possible improvements of the current transmitting and receiving structure, paving the path for wireless power transfer topologies

In conclusion, despite having obtained in eCo-FEV good preliminary small-scale evaluation results, it is foreseen that to complete the performance evaluation of the system, a piloting project would be necessary.

Furthermore the technical solution adopted for inductive charging seems to be feasible although more research and development activity is needed to test it in a realistic scenarios, with more long lasting functional tests as innovative solutions require.

9 References

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[5] eCo-FEV Deliverable D300.5, System design-integration-technical validation .

[6] eCo-FEV Deliverable D400.1 Evaluation methodology, test and evaluation plan.

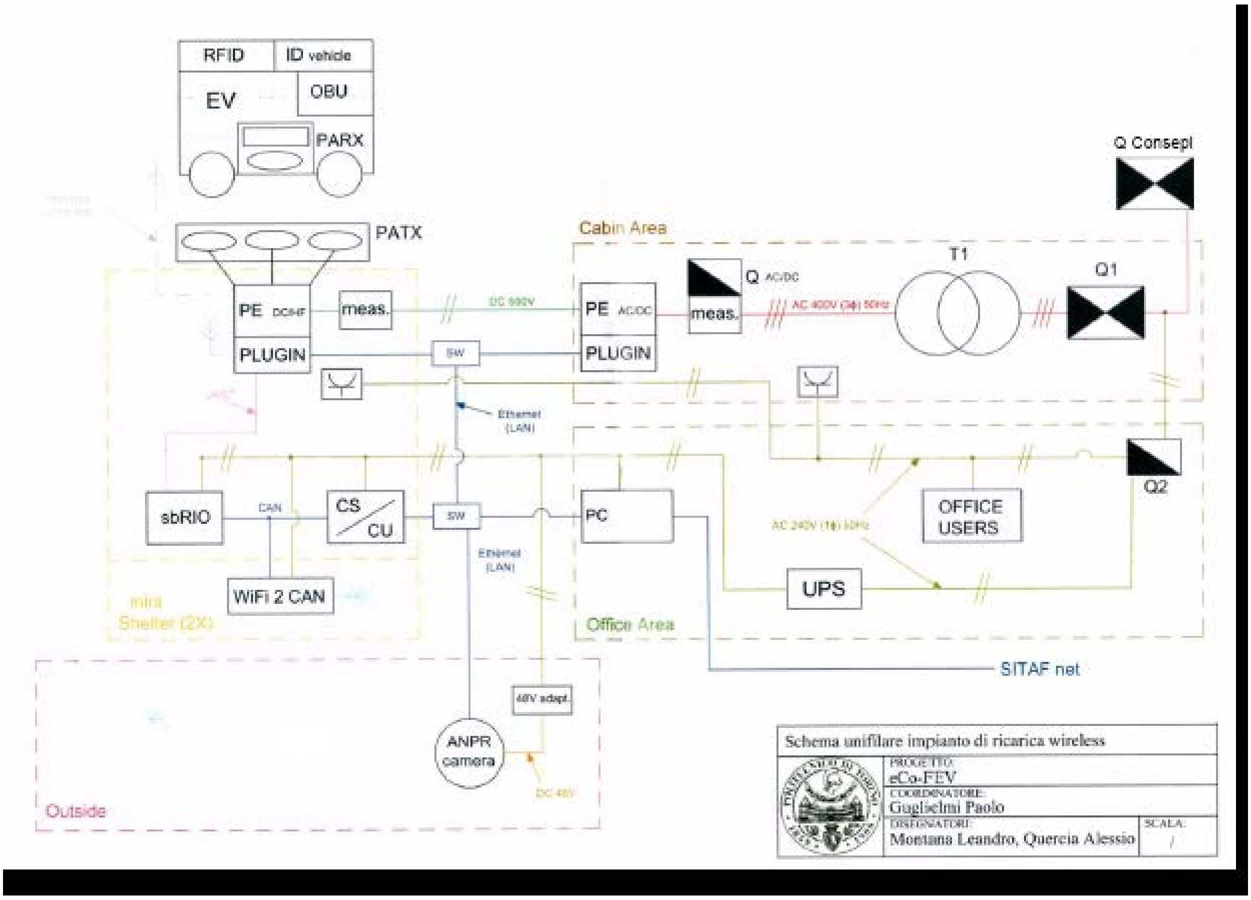
10 List of Abbreviations

AAA	Authentication, Authorization, Accounting
AC	Alternating Current
API	Application Programming Interface
AU	Application Unit
BTP	Basic Transport Protocol
C2CCC	Car to Car Communication Consortium
C-ITS	Cooperative ITS
C/S	Charging Station
C/S CU	Charging Station Control Unit
CALM	Communications Access for Land Mobiles
CAM	Cooperative Awareness Message
CAN	Controller Area Network
CCU	Communication Control Unit
CEN	European Committee for Standardization
CI	Charging Infrastructure
CN	Correspondent Node
CoAP	Constrained Application Protocol
CWD	Charging While Driving
DC	Direct Current
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short Range Communications
ECU	Electronic Control Unit
ETH	Ethernet
ETSI	European Telecommunication Standard Institute
EV	Electrical Vehicle
EVCC	Electric Vehicle Communication Controller
EVSE	Electric Vehicle Supply Equipment
FEV	Full Electrical Vehicle
G5	Telecommunication technology of vehicular ad hoc network
GNSS	Global Navigation Satellite System
HV	High Voltage
HMI	Human Machine Interface
HTTP	Hypertext Transfer Protocol

HTTPS	HTTP Secure
HW	Hardware
ID	Identity
IEC	International Electrotechnical Commission
ICE	Internal Combustion Engine
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
ISO	International Organization for Standardization
Ipv6	Internet Protocol version 6
ITS	Intelligent Transportation System
ITS-S	ITS Station
IVI	In Vehicle Information
LDM	Local Dynamic Map
M2M	Machine to Machine
MIPv6	Mobile Ipv6
NEMO	Network Mobility
OBU	On Board Unit
OEM	Original Equipment Manufacturer
OSGi	Open Services Gateway initiative
PLC	Power Line Communication
PoI	Point of Interest
POTI	Position and Time
REST	Representational State Transfer
RSU	Road Side Unit
SAE	Society Of Automobile Engineering
SAM	Service Announcement Message
SECC	Supply Equipment Communication Controller
SLA	Service Level Agreement
SOAP	Simple Object Access Protocol
SoC	State of Charge
SoH	State of Health
SW	Software
TC	Technical Committee
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UML	Unified Modelling Language

UMTS	Universal Mobile Telecommunications System
URL	Uniform Resource Locator
V2G	Vehicle to Grid
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VDP	Vehicle Data Provider
VPN	Virtual Private Network
VRM	Vehicle Relationship Management
WWW	World Wide Web
XML	Extensible Markup Language

Annex 1 Certification equipment conformity Italian test site



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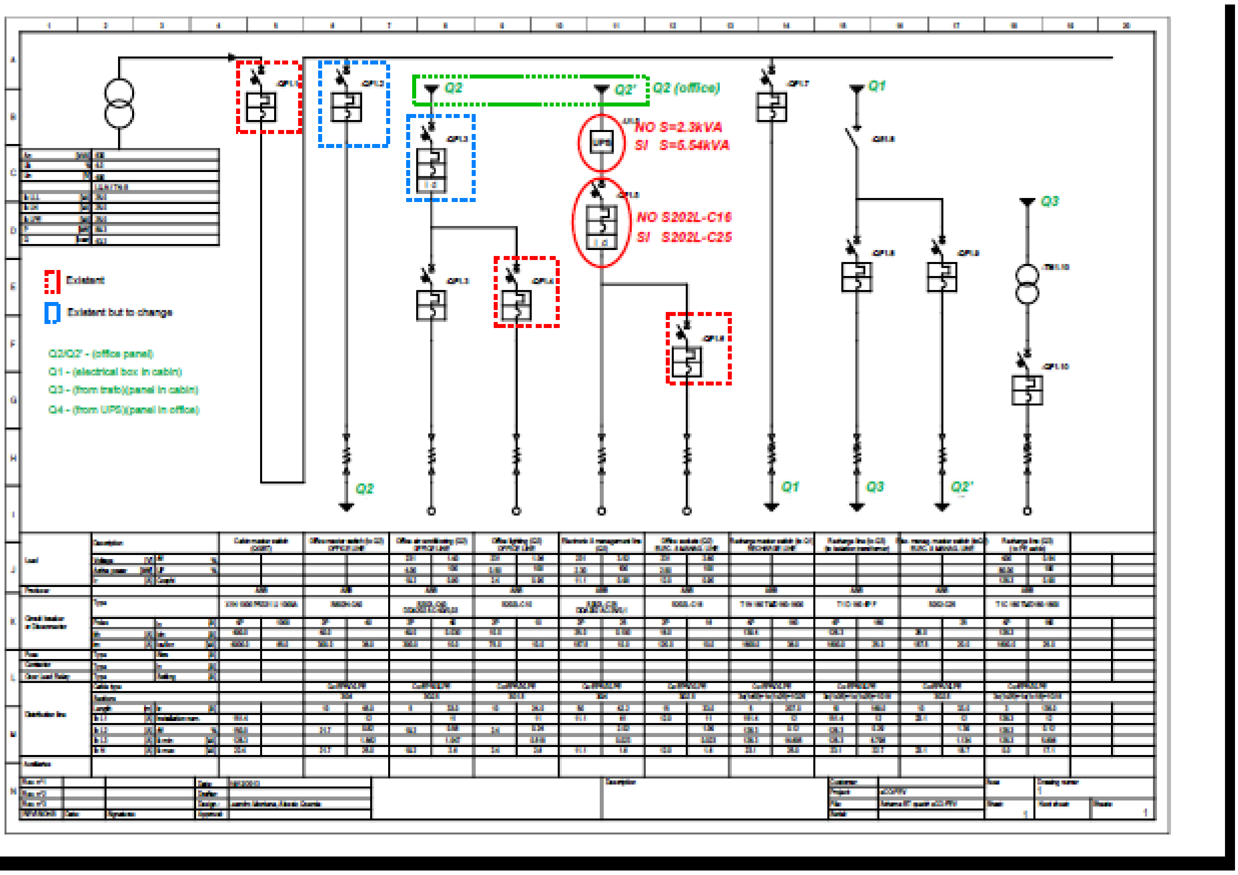
Q2
Q2'
Q2 (office)
Q1
NO S=2.3kVA
SI S=5.54kVA
NO S202L-C16
SI S202L-C25
Q3
Existent
Existent but to change
Q2/Q2' - (office panel)
Q1 - (electrical box in cabin)
Q3 - (from trafo)(panel in cabin)
Q4 - (from UPS)(panel in office)
Q2
Q1
Q3
Q2'