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Impact of Interdisciplinary Research on Planning, Running, and Managing Electromobility as a Smart Grid Extension

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ABSTRACT The smart grid is concerned with energy efficiency and with the environment, being a countermeasure against the territory devastations that may originate by the fossil fuel mining industry feeding the conventional power grids. This paper deals with the integration between the electromobility and the urban power distribution network in a smart grid framework, i.e., a multi-stakeholder and multi-Internet ecosystem (Internet of Information, Internet of Energy, and Internet of Things) with edge computing capabilities supported by cloud-level services and with clean mapping between the logical and physical entities involved and their stakeholders. In particular, this paper presents some of the results obtained by us in several European projects that refer to the development of a traffic and power network co-simulation tool for electro mobility planning, platforms for recharging services, and communication and service management architectures supporting interoperability and other qualities required for the implementation of the smart grid framework. For each contribution, this paper describes the inter-disciplinary characteristics of the proposed approaches.

INDEX TERMS Smart grid, co-simulation, electro mobility, power distribution, service infrastructure, Internet of Things, arrowhead.

I. INTRODUCTION

The Manheim village is an area of the city of Kerpen in North Rhine-Westphalia[1] in Germany which represents a clear example of the application of new concepts for the organization of the cities of tomorrow. This small village will be completely relocated until the year 2020 as it is located within the area of the surface mining area ''Hambach'' by RWE. The mining area will have reached the boundaries of Manheim village in 2022 to exploit brown coal which is located at a maximum depth of 370 m below ground level, featuring a coalbed with up to 100 m thickness. The excavation residues form an elevated dump called ''Sophienhoehe'' which, with an altitude of 200 m over ground, claims to be the highest hill ever formed by mankind. After operation end, the refilled remaining abandoned open pit will be flooded by pipelines from river Rhine, forming an artificial lake (Figure 2)[2] with a surface of 42 km^2, a maximum depth of 400 m and a water volume of 3.6 billion m^3 i.e., the second biggest lake in Germany after the Bodensee. The inhabitants of Manheim

[1]http://dict.leo.org/ende/index_de.html#/search=Rhine-Westphalia&searchLoc=0&resultOrder=basic&multiwordShowSingle=on

[2]Courtesy of Matthias Popp - Storage for a secure Power Supply from Wind and Sun and Joachim Schwister ''SpeicherStadt Kerpen'', Vortrag des Technischen Beigeordneten, 25.06.2015 - Siemens, Erlangen.

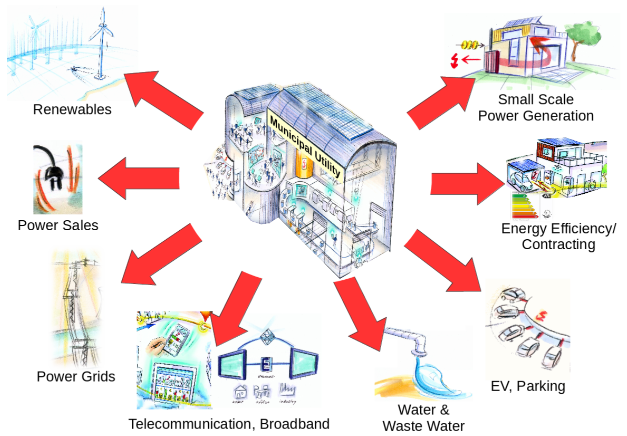


FIGURE 1. Plan for the territory of Manheim-neu.

FIGURE 2. The artificial lake.

village (ca. 1500 people) were forced to relocate by law and decided by the majority to move to a new area close to Kerpen and build a new village called Manheim-neu. They try to preserve their traditions, values and social tissue and at the same time have an outstanding development plan based on the smart grid and related industries and services. At present this new village is in the construction phase and the inhabitants envision a future of sustainable growth, expecting to rise attractiveness and investments and avoiding for future generations a similar devastating degradation of their territory triggered by fossil fuel energy systems. This vision originates by the combination of the population feelings joined to a smart grid centered culture.

Figure 1 depicts the plan for the new territory which is built around a large borrow-pit where coal was removed from along the years. The borrow-pit is to be transformed into a beautiful lake. Water is pumped in the lake from the spare energy produced by renewable energy sources (RESs) in the area. A hydroelectric plant generates energy out of the water lake to compensate the energy needs when locally available RESs do not meet the territory energy requirements. Energy efficiency is ensured by smart static and dynamic energy management at public and private premises. Electro Mobility is adopted by citizens as well as by private enterprises and public institutions. The plan for the territory includes a set of complementary actions to increase the quality of life and the territory attractiveness around this smart grid based nucleus. The energy system and its business are reshaped at a quite fine granularity level, most of the energy needs is produced locally and using RESs by holding the overall energy balance near zero.

The smart grid deployment in the area calls for innovation in the following domains:

1) distribution in a decentralized administrative unit formed by eight municipalities.
2) Short-term multimodal energy storage on various levels to shift renewable energy from day to night.
3) Long-term multimodal energy storage to shift renewable energy from summer to winter.
4) Business models for the newly founded municipal utility of Kerpen to permit a cost-covering operation of the power and energy grids while providing attractive pricing and enhanced comfort for the inhabitants of Kerpen.
5) Management of decentralized energy production Integration of large-scale e-mobility into the energy management and storage concept by financial incentives and by moving the vehicle fleet operated by city of Kerpen towards electric vehicles.
6) Energy efficiency measures on all levels to reduce the amount of energy consumed by residential, office and industrial buildings as well as other stand-alone devices connected to the city grid. This is accompanied by contracting which stimulates their energy-efficient operation.

The advances planned by Manheim-neu can be seen as just the beginning of a renewal process bringing the entire community to innovative models of energy distribution, mobility, and energy market. The progress is not limited to the energy world, but a series of applicative and research fields are being developed as well in scenarios, often involving energy distribution, storage, smart usage and saving. The municipality of Kerpen decided that the solution to overcome their unacceptable environmental conditions was to take the smart grid as the pillar of their industrial, social and environmental renaissance. Taking this as the background, we will discuss about the benefits that joint work of interdisciplinary teams may bring in smart grid research and smart grid based innovation in such a case.

Cloud computing, pervasive computing and Internet of Things (IoT) provide examples of the instruments to check and control the increasing number of observing and actuating devices in order to improve the context awareness and, consequently, the adaptability of system parameters to situations. Device to cloud approaches, based on the advances provided by the IoT together with Semantic Web (SW) information representation technologies, allows Machine to Machine (M2M) automatic interaction among devices and software artifacts, without human intervention. Service oriented architectures (SOA), mobile applications and device to cloud infrastructures contribute to the technological basis over which a large scale energy management system can be built. The user satisfaction, deriving from the usage of advanced services, simplifies and accelerate the transition to a system radically different from the affirmed one by limiting the impact of the transition and the typical anxiety due to the changes. Several fields of knowledge previously developed separately at industrial and research level are now converging in what is commonly referred to as Smart Grid (SG), a large scale energy management infrastructure involving all actors related to energy production, distribution, storage and usage as well as the surrounding service ecosystem and information management infrastructure. The generalized interest on these topics and on the potential achievable by their interaction is also confirmed by congruous investments from the European community in several IP projects spread in recent years. The results achieved by the first projects have been reused and optimized to make the SG vision more concrete and to increment the technology readiness level of the hardware and software prototypes. This paper presents, in the context of the author's SG vision, a set of concepts, software artifacts and simulation environments belonging to different domains, but working together in order to provide results overcoming the limits imposed by single-domain approaches. For example, a simulation model of a parking lot providing energy to electric vehicles is significant, however the obtained results will be much more relevant if an Electro Mobility simulator provides realistic flows of vehicles depending on traffic conditions. In the domain of mobile applications, a stand alone charging spot reservation service may enhance user experience with electric mobility, but there are questions whose answer is possible only in an integrated environment including also traffic and the power grid e.g.: how much a charging spot reservation service affects the traffic? Does a reservation made during energy consumption peaks require an energy amount affordable for the power grid? The test environment and the simulation infrastructure described in this article have been developed incrementally during several years of collaboration among heterogeneous academic research groups, working in close contact with industries in the context of European Projects. The timespan of the research ranges from 2008, when the techniques for the representation of machine interpretable information have been studied in the SOFIA[3] project, to the present when, in the European project Arrowhead,[4] the technology readiness level of the implemented systems is being incremented and the deployment of the simulated infrastructure in the real world is being actuated by using performing technologies to manage the service layer and the big data generated by the many heterogeneous interacting entities. Among the project under which the vision and the test prototype have been conceived and developed, it is relevant to cite also Internet of Energy (IoE)[5] and the Knowledge and Innovation Community of the European Institute of Innovation and Technology (EIT) ICT project of 2014 ''Planning Tool for EV Deployment and Related User Centric Services'', where the collaboration with industrial partners like ENEL, Siemens, Centro Ricerche Fiat (CRF) and Eurotech helped the academic groups to be grounded on the specific industrial needs and requirements.

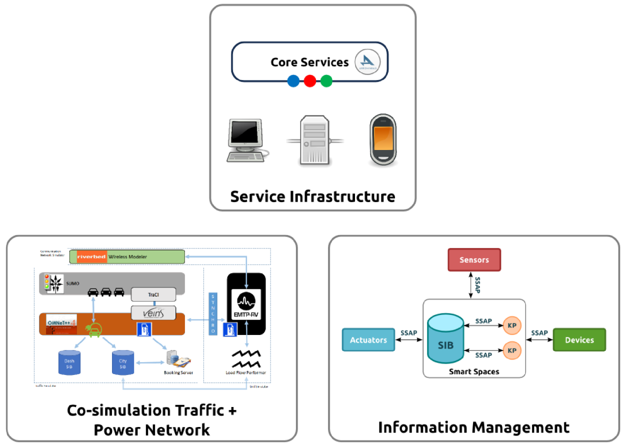


FIGURE 3. Schematization of the implemented infrastructure.

Figure 3 sketches the implemented test suite which will be detailed in the rest of this work and enlightens three main cooperating frameworks: the information management and communication framework, the Electro Mobility and power network co-simulation framework and the service layer. Each framework includes one or more domains of knowledge and provides its own results but, even if the present research work is mainly focused on Electro Mobility, the most interesting results derive from inter-disciplinary inter-framework and intra-framework cooperations. Among the results that could not have been achieved without the co-operation of inter-disciplinary teams, the most relevant are those related to the interaction between Electro Mobility, power network and services, such as:

1) interplay between Electro Mobility penetration rates and charging spots power, density and distribution.
2) impact on the traffic of mobile services simplifying the discovery and usage of the recharging infrastructure (e.g. reservation services and route planners)
3) impact of Electro Mobility on the power network
4) possibility to analyze different power network configurations and sizing in relation to Electro Mobility and renewable sources (i.e. pre deployment analysis)
5) usefulness of vehicle to grid (V2G) and local storage facilities in the application of regulation services or other countermeasures to avoid power grid congestion during power request peaks
6) impact of the limitations imposed by the grid to the mobile services (e.g. variable price of reservations

[3]http://www.artemis-ju.eu/project/index/view?project=4
[4]http://www.arrowhead.eu/
[5]http://www.artemis-ioe.eu/

depending on the estimated available power in the reserved time).

Among the results presented above, some of them (e.g. 1-4) are presented and discussed in this article, while others (e.g. 5 and 6) are left for future research.

The first part of this article describes the research work that has been carried out on the three main research topics depicted in figure 3. The information management and communication framework, detailed in section III, provides the basis for a mutual understanding between all the interacting entities: from the specificities of communication technology to the abstraction of semantics in a common ontology referenced vocabulary.

The Electro Mobility and power network co-simulation framework will be detailed in section IV. This section has a central role as in it converges the expertise of the whole research groups: as it will be explained most of the more relevant results will be possible only thanks to the cooperation of the three frameworks and from that of the two distinct simulators in the co-simulator context.

Section V will describe a set of implemented SG related services in the sub-domain of Electro Mobility and discusses about their interaction with the co-simulator framework thanks to a flexible interface based on information semantics.

The last sections of this article describe concepts and initial results obtained in the technological deployment phase. Both sections VI and VII are driven by the Arrowhead project vision, but while in section VI the focus is in the strong bind between the SG and the IoT concepts, section VII describes the device to cloud infrastructure for the SG, focusing on high level concepts. Finally conclusions are drawn in section VIII.

II. RELATED WORK

This section provides a brief review of the related works starting from information management and communication, then analyzing the main works related to the service framework dealt with in this paper.

A. ELECTRO MOBILITY

Due to the meaning that EM has gained for both car manufacturers and customers [1] and to the sudden change they may bring to the economy, the acceptance of such an innovation has been found to be quite limited [2]. These difficulties are due to several sources of dissatisfaction among both users and enterprises.

One of the main problems is the scarcity of adequate infrastructures. Indeed, the low amount of public charging stations nowadays up and working in several European countries raised a problem of overcrowding and availability. Furthermore, private drivers often feel skeptical when dealing with such a big change in their habits. One of the most noticeable reasons is the range anxiety, for which drivers are afraid of having a too low battery level in order to reach their destination. From the energy vendors' viewpoint, Electrical Mobility is a new source of consumption and may bring a deep impact on the distribution grid.

Initially there have been sparse and small efforts[6] in avoiding issues like charging stations overcrowding. In order to correctly schedule recharges in public charging stations, a reservation infrastructure is necessary in order to avoid user dissatisfaction and pointless waiting queues. With the advent and the diffusion of smart devices, such a solution has been largely fostered. In [3] a re-routing service has been introduced, largely using the concept of reservations and load balancing showing that, at the cost of a slightly longer trip, a correct vehicle scheduling results in an overall benefit. Compared with this approach, our proposal intended to completely yield the decision on which station to choose to the user.

A similar research is shown in [4], where a recommendation system is implemented considering the current status of the recharging infrastructure.

Out of the most successful research attempts to gather all aspects of an urban mobility scenario so far is the SUMO project [5], which has been carried out providing an efficient tool for traffic modeling. Currently, it supports microscopic vehicle characterization, route planning and simulation of arbitrarily big traffic networks which can be imported from different well-known distributors such as OpenStreetMap. Its flexibility of use led to its application to various and heterogeneous research projects for which it constitutes a predominant choice.

From a completely different point of view, a number of challenges for power grid infrastructures are commonly raised by the increasing exchange of renewable energy in Europe. Such challenges include, for instance, congestion avoidance and power grid stability. Although the topic is quite recent, there have been already solid studies linking the concept of Smart Grid to the Electrical Mobility. One of the most famous is the concept of vehicle-to-grid recharge, introduced for the first time in 1997 [6], in which the battery of an electric vehicle is seen as a source of energy on demand. The concept enables a whole new viewpoint against the market of energy, since energy might be sold by privates as well.

Joint simulations of Smart Grid load balances and Electrical Mobility have been frequently explored over the last years from different viewpoints. There have been further studies on the minimization of waiting time for electric vehicles in charging stations modeled as parking lots [7]. This led to algorithms exploiting well-known scheduling policies in orderd to maximize the amount of vehicles fulfilling their requirements.

B. COMMUNICATION TECHNOLOGIES

The increasing demand of communication flexibility has led in recent years to the introduction of the concept of HetNet,

[6]Carstation Project, "Carstations - find your charge", http://www.carstations.com"

where multiple heterogeneous communication systems are designed in order to cooperate within a certain area [8]. The information sources are diversifying even more, especially with the introduction of sensors and devices; this leads to the introduction of the so-called Machine Type Communications (MTC) or Machine-to-Machine (M2M) communication characterized by low throughput intermittent traffic [9]. Both HetNet and M2M concepts are at the base of the forthcoming 5G communication systems [10].

Among different M2M applications, the Smart Grid has specific requirements [11] and the interest for management of electricity nodes by exploiting a wireless infrastructures is increasing [12], [13].

Hence, in the last years, several proposals have been done for allowing efficient M2M communications for Smart Grid applications by exploiting HetNets. In [14], the authors propose to use a heterogeneous WiFi/WiMAX solution for allowing an efficient interconnection of the metering devices. In [15], a solution based on a LTE-A HetNet for Smart Grid application is proposed. In [16], the authors survey on the most important challenges for planning future wireless communication infrastructures for Smart Gird applications while coping with their different requirements.

C. SERVICES

Information and Communication Technologies (ICT) plays a fundamental role to support the operations of EV drivers, e.g. by providing information about charging opportunities along the path toward a destination, so that the well-known anxiety problems related to the utilization of an EV can be largely mitigated [17]. Several software services have been proposed for EV-related scenarios, by using traditional Web-based, or mobile-based technologies. Regarding the Web-related services, we cite the ChargeMap[7] and PlugShare[8] websites, that allow displaying the available charging stations, namely EVSEs (Electric Vehicle Supply Equipments), on a target area, with charging profile and availability state of each station. Mobile applications for EV scenarios are becoming more and more popular, due to the pervasiveness of mobile devices like smartphones or tablets, equipped with Internet connectivity and geo-location capabilities. Several EV manufacturers provide mobile applications for their vehicles. This is the case of VOLVO[9] or NISSAN,[10] whose applications allow the remote monitoring of the EV's charge state, and the estimation of the driving range. As the excessive proliferation of software, technologies and data formats specific for an EV model is unwanted, several general purpose mobile-based services have been proposed in the literature. We can classify the existing applications into three main categories: profilers, route planners, or EVSEs charging reservation systems. Profiler applications like [18] attempt to determine the EV driver's guide-style, in order to provide feedbacks on current driving efficiency. Route planners are important due to the poor coverage of EVSE infrastructure on several areas of the world, which translates into the need of an accurate estimation of the driving range, and of a careful planning of the charging stops. We cite works like [19]–[21] where the classical shortest path problem is revised for the EV-related scenario, by taking into account energy minimization issues, regenerative breaking functionalities and planning of charging stops. Finally, the third category (including among others the software described in [22] and [23]) allows displaying the available EVSEs close to the EV's location, and possibly reserving the utilization of charging slots in advance. Although most of the applications described so far can provide useful services from the perspectives of both EV drivers and EVSE infrastructure providers, their viability is limited by two main factors. First, they do not take into account data interoperability issues, i.e. the fact that EV-scenarios are complex environments characterized by the presence of different stakeholders (e.g. EV manufacturers, EVSEs providers), each utilizing a specific data format. Second, their effectiveness on large-scale scenarios, and potential impact on EV drivers have not been carefully evaluated. In Section V-E, we discuss how we have addressed both these limitations thanks to an interdisciplinary approach, involving software architecture design, data design, mobile application deployment, and co-simulation techniques.

D. SDN IN THE IoT SCENARIOS

The benefits of employing Software Defined Networking (SDN) techniques in IoT environments is becoming recognized in multiple domains, not only in intelligent transportation systems. For example, [24] developed a robust control and communication platform using SDNs in a smart grid setting. Similar efforts have been explored in the smart home domain where IoT devices are extremely heterogeneous, ranging from traditional smartphones and tablets, to home equipment and appliances with enhanced capabilities. Recent efforts include a home network slicing mechanism [25] to enable multiple service providers to share a common infrastructure, and supporting verifying policies and business models for cost sharing in the smart home environment. At a lower device level, [26] employs SDN techniques to support policies to manage Wireless Sensor Networks. In summary, while there is significant interest in managing IoT environments, many of the efforts in this direction are isolated to specific domains, or a specific system layer. The proposed work employs a layered SDN methodology to bridge the semantic gap between abstract IoT task descriptions and low level network/device specifications. For the interested readers, in [27] we additionally discuss the key differences between SDN techniques in traditional Data Center Networks and in IoT environments, by further motivating our novel IoT SDN controller whose primary guidelines of design and implementation are described in section VI.

[7] http://chargemap.com/

[8] http://www.recargo.com/plugshare

[9] https://play.google.com/store/apps/details?id=se.consat.myev&hl=en

[10] http://www.nissanusa.com/electric-cars/leaf/owner-questions/ev-mobile-app

III. INFORMATION MANAGEMENT AND COMMUNICATION FRAMEWORK

This Section briefly reviews the optimization of the communication among SG nodes through wireless technology, and the semantic information management tool we used to achieve interoperability among heterogeneous entities.

All the work performed in the information management and communication framework is relevant to the SG as, without proper solutions and optimizations in the communication layer, it would be impossible to deal with SG scenarios involving several heterogeneous nodes. Furthermore, once the communication issues have been solved and the interacting entities are able to exchange messages, the different multi-vendor legacy data sources need to be managed at information semantics level, in order to grant the mutual understanding and the interoperability.

A. SG HETEROGENEOUS COMMUNICATION INFRASTRUCTURE

The goal of the SG communication infrastructure is to ensure that all the information incoming from the sensing nodes and control entities can reach all the nodes of the SG network and the interface nodes toward the cloud infrastructure. To this aim a reliable, universal, and secure communication infrastructure together with an efficient robust network architecture, able to manage operations and control of the SG, should be designed.

Different types of communication systems can support SG applications: we will focus on wireless communications due to their inherent advantages in terms of flexibility and simple installation. One of the most important characteristics of the wireless scenario is that multiple wireless communication systems can be deployed in the same area.

It is possible to categorize three main SG networking scenarios: Home Area Networks (HAN), Neighbour Area Networks (NAN), and Wide Area Networks (WAN). The HAN refers to short-range scenarios, usually characterizing the interconnection of nodes within a single-building. This type of communication usually refers to the interconnections among in-home environmental sensors, in-home power generator (e.g., solar cells) and in-home metering stations. The aim of the HAN is to monitor the energy consumption/generation through short-range wireless networking like Zigbee, Wi-Fi, Bluetooth. The NAN refers to a neighbouring scenario that can be seen as a group (or cluster) of HAN usually modelling a group of neighbor houses; the typical wireless interconnections are WiFi Direct/WiFi, LTE, WiMAX and Satellite links. The WAN is modelling the interconnections among multiple NAN and with the centralized energy generating farms (e.g., renewable energy farms, fossil fuels/nuclear plants) for monitoring and managing a countrywide infrastructure; the typical wireless infrastructures are cellular/broadband area networks and satellite systems.

Hence, on one hand, we have several different types of SG nodes randomly placed within a certain area, each one characterized by different requirements, and, on the other hand, the area could be covered by one to many different wireless technologies having different characteristics. The best communication infrastructure setup would avoid redundant costs and inefficient usage of the communication resources. The huge number of smart meters and users producing data in a certain period, should be managed in a way that allows the respect of the service requirements of each type of node. Our effort is directed towards the definition of a proper cost function able to respect the requirements of the SG nodes by selecting the best wireless communication system for each deployment scenario and each time.

B. COST FUNCTION MODEL

A proper cost function could be defined for evaluating (and minimizing) the cost of the selected connections between the nodes and the wireless access points in the considered environment.

As previously introduced, the problem of selecting the most appropriate connection between nodes and access points is the result of the matching between the node requirements and the wireless networks properties. To this aim the cost function to be used will take into account both networking and users perspectives.

Let us focus on a scenario where several Radio Access Networks (RAN) have been deployed. A RAN identifies a specific technology: WiFi, LTE. WiMAX, Satellite, etc. Each RAN can be deployed by using a variable number of Base Station/Access Point (BS/AP), depending on the coverage area of each technology. The higher is the coverage area, the lower is the BS/AP density. Each BS/AP has a set of networking side Key Performance Indexes (KPIs) to be respected. The networking side KPI could include the maximum number of users per BS/AP, the deployment cost, the service availability.

Similarly to the previous case, each type of node has its own KPI representing the requirements in terms of, e.g., delay, throughput, blocking probability that should be respected. Hence, the network total cost can be modeled as:

$$\begin{aligned} C_{NT} = & \frac{1}{W_o + \sum_{f=1}^{N_f}} W_{u_f} \\ & \times \Bigg[W_o \frac{1}{\sum_{r=1}^{N_{RAN}} W_{o_r}} \sum_{r=1}^{N_{RAN}} W_{o_r} \\ & \quad \times \left(\frac{1}{N_{BS_r}} \sum_{b=1}^{N_{BS_r}} \left(\frac{1}{\sum_{i=1}^{N_{KPI_r}} W_{r,i}} \sum_{i=1}^{N_{KPI_r}} \left(W_{r,i} Kbs_{r,i} \right) \right) \right) \\ & \quad + \sum_{f=1}^{N_f} W_{u_f} \frac{1}{N_{u_f}} \times \sum_{n=1}^{N_{u_f}} \\ & \quad \times \left(\frac{1}{\sum_{i=1}^{N_{KPI_{u_f}}} W_{u_f,i}} \sum_{i=1}^{N_{KPI_{u_f}}} \left(W_{u_f,i} Ku_{u_f,i} \right) \right) \Bigg] \end{aligned} \tag{1}$$

where:

- W_0 is the operator weight;
- W_{uf} is the weight of the f-th SG application;
- N_f is the number of SG applications
- N_{RAN} is the number of radio area networks
- W_{or} is the weight of the RAN r
- $N_{BS\,r}$ is the number of base stations/access points for the RAN r
- $N_{KPI\,r}$ is the number of KPI for the RAN r
- $Kbs_{r,i}$ is the i-th KPI of the RAN r
- $W_{r,i}$ is the weight of the i-th KPI for the RAN r
- N_{uf} is the number of users of application f
- $N_{KPI\,uf}$ is the total number of key performance indicators for the f-th applications
- $W_{uf,i}$ is the weight of the i-th KPI of the f-the application
- $K_{uuf,i}$ is the i-th KPI for the users belonging to the f-th application.

The above defined cost function allows to take into account the KPIs of the different RANs and SG application opportunely weighted by ad-hoc parameters. The weight parameters ranges from 0 to 1 identifying an high (with 1) or low (with 0) importance for the selected KPI. Furthermore, the KPIs are normalized values ranging from 0 to 1; if the normalized value is 1 means that the value is the worst possible, while 0 means that the optimum value is reached. Thus, it is clear that the lower the cost the closer the system is to the optimum value.

The weighted sum of the KPI for each node and each BS composing the RANs allows to define an overall cost of the network where both the networking and the nodes are taken into account.

The above defined cost function can be used within a certain Radio Resource Management algorithm aiming to allocate each SG node to a specific BS for minimizing the overall cost. The main problem is that there are a lot of configurations which should be considered for respecting the SG requirements; hence the problem moves to optimize the KPI for the selected inputs. The approach we followed was of iterative nature: a first rough radio resource allocation is employed after the smart grid and the RAN scenario definition that is based on the positions of the SG nodes and of the RAN base station.

Then a basic algorithm (e.g., the nearest AP selection or the higher capacity selection) is performed to obtain a first cost function evaluation. Eventually the process continues by optimizing the radio resource allocation based on the selected constraints, until a minimum value for the cost function is reached. This empirical approach allow to minimize the cost function by selecting the most appropriate allocation of each SG node.

C. SEMANTIC INTEROPERABILITY

In order to manage information semantics among different interacting entities, we used technologies and techniques aiming to obtain three main high level features which are also requirements of the SG vision described in this work:

1) the interoperability, because many heterogeneous entities (devices and programs) developed independently by multiple vendors should cooperate and share their status and controlling interface with intelligent coordinating agents;
2) the publish subscribe-paradigm which is a base feature for reactive systems that need to make clients immediately aware of changes happened server side and a cheap band occupation since data is sent only when needed and polling is avoided;
3) the extendibility of the information model. It is very important, in particular with innovative software architectures, to have the possibility to build extensions with no impact on what has been previously implemented.

It is widely recognized that the evolution of the power grid into the SG requires the support of technological infrastructures to handle the exchange of a huge amount of data among a high number of distributed and heterogeneous entities. As highlighted in [28], such infrastructures cannot be developed in a monolithic way, but should rather be designed as multi-component system to facilitate re-usability, to reduce integration costs, and to offer the suitable level of abstraction. Several categories of middleware exist [29]. The Message-Oriented Middleware (MOM) paradigm is emerging as a reasonable choice for smart grids, thanks to high scalability, loose coupling between entities, ability to provide synchronous and asynchronous communication, and support for differentiated priority levels. Considering the MOM category, a further distinction into three subcategories can be done in relation to the communication paradigm: message passing, message queuing and publish-subscribe. By using message passing there is direct, i.e. performant, communication among agents but poor level of decoupling. In message queue the information producers write in queues of messages which are then accessed by information consumers in ascending chronological order. Publish subscribe middlewares allow asynchronous interaction by letting the information consumers being contacted by the middleware itself when new relevant data are available, decoupling is maximized as all the interacting agents need only to be interfaced to the middleware, in order to interact.

In our information management framework we have chosen a semantic publish-subscribe data oriented middleware solution: Smart-M3 [30] (Figure 4). Smart-M3 was conceived and prototyped between 2009 and 2011 in the context of the European project SOFIA and is now constantly maintained and updated with new features by a large international community. The abstract software architecture is quite simple and based on two components and their communication protocol. The central node of the architectural model is called Semantic Information Broker (SIB), which manages semantic knowledge and the access to it through a set of primitives for reading, writing and subscribing to set of triples (i.e., semantic sub-graphs). The interacting agents are referred to as Knowledge Processors (KP), they can be information producers, consumers or both depending

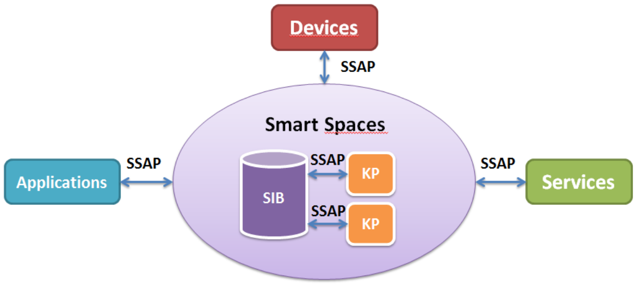


FIGURE 4. Architecture of the Smart-M3 interoperability platform.

on their role. Thanks to the simplicity of the architectural model devices, which are heterogeneous for computational power and technology, can be interfaced to a Smart-M3 based system with the only requirement of making an adapter KP. Its function is to interact with the knowledge base according to a defined domain ontology.

In our multi-framework infrastructure Smart-M3 is used by all the interacting entities (i.e. vehicular simulator, power network simulator and services) and at their interfaces. The mutual understanding is granted by a domain ontology, developed on purpose, which is extendable when new modules will be integrated. For the sake of space and of focus on the main topics covered by this article we will not provide here details on the semantic description of the defined concepts and KP interaction, but we refer the interested reader to research work where Smart-M3 has been successfully applied to other multi-disciplinary domain of interest like the tele-monitoring in public health scenarios [31] and the maintenance of large buildings [32].

IV. CO-SIMULATION PLATFORMS OF URBAN TRAFFIC AND DISTRIBUTION POWER NETWORKS FOR INFRASTRUCTURE PLANNING AND CONTROL DESIGN

This section describes a simulator obtained by the interface between the traffic simulator SUMO (simulation of urban mobility) and the power network simulator EMTP[11] (electromagnetic transient program). SUMO has been adapted to represent the electric vehicles storage characteristics. EMTP includes the model of aggregated EVSEs (electric vehicle supply equipment).

The developed simulator allows the analysis of urban traffic including a significant percentage of electric vehicles and several charging stations (with particular reference to clusters of fast charging stations concentrated in public parking lots). The detailed representation of both the booking system described in section V-B aiming at scheduling the recharge process of each vehicle and the effects of the electric vehicles charging on the power distribution network are also included in the simulator. The booking system, grants the correct scheduling of the recharge processes of plug-in electric vehicles (PEV), i.e. of both battery-based vehicles (BEVs), without an internal combustion engine, and plug-in hybrid vehicles (PHEVs), which have an internal combustion engine other than the electric motor.

[11]http://emtp.com/

The co-simulator platform described in this section has been built in order to meet the following goals:

1) design a distributed control able to mitigate the congestions in the network caused by an excess of power demand by the recharging of electric vehicles;
2) compare different schedule procedures of the recharge processes by using a booking system in order to minimize the research of an available charging station and the waiting queues at the charging stations.

This section provides a description of the architecture of the co-simulation platform and of its components, reviews the main characteristics of a distributed control algorithm that allows both the congestion management of the network and the reduction of the charging effects on voltage variations, and illustrates the type of analysis carried out by using the simulator through the presentation of some results.

A. ARCHITECTURE OF THE CO-SIMULATION PLATFORM

As presented in [33], the co-simulation platform integrates the traffic simulator, the power distribution simulator and the communication network simulator. The three simulation environments are described in the following subsections. Figure 5 illustrates the general architecture of the co-simulation environment, whilst fig. 6 describes the synchronization between the traffic and power distribution network simulator.

We chose Smart-M3, explained previously in section III-C, as the interoperability platform (in Figure 5). In particular, the City SIB collects information regarding all the entities coming from different domains, while the Dash SIB collects data regarding the vehicles. Thus, the simulators, the simulated vehicles, the simulated charging stations and the City Service Processor are themselves KPs.

The time integration between traffic and power network simulators is realized through a TCP server built in Python, with the role of a semaphore which regulates the synchronization of the simulation flow.

1) TRAFFIC SIMULATOR

The urban traffic is modelled using VeinS, which is an open source framework for vehicular network simulations based on two simulators, namely discrete event-based simulator OMNeT++ and road traffic simulator SUMO. SUMO (Simulator of Urban Mobility) is an open source traffic simulator capable of modeling entities such as roads, vehicles, traffic lights and vehicle routing. Each entity is simulated microscopically, thus it is possible to interact with them separately. OMNeT++ is a general purpose simulation environment for communications, which is able to model customizable and interoperable modules. For our analysis, we considered a large-scale scenario (i.e. the downtown of Bologna), with a realistic street map (imported from the OpenStreetMap project). In particular the simulation relies on a running instance of SUMO that takes as input the road map of the city,

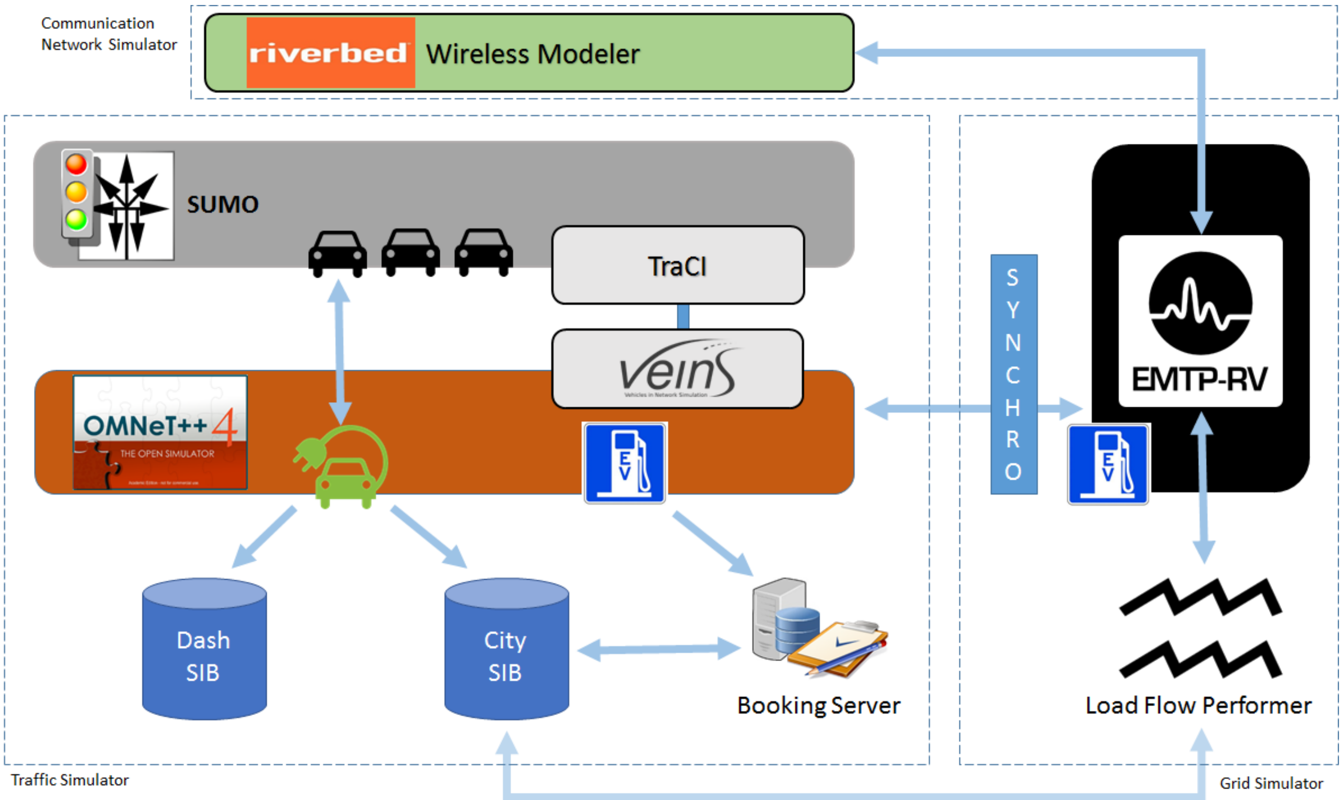


FIGURE 5. Architecture of the co-simulation environment.

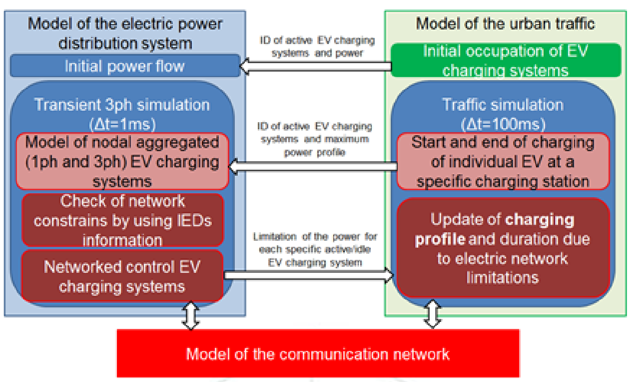


FIGURE 6. Data synchronization and exchange between traffic and power network simulators, communication simulator and power distribution simulator.

including traffic lights, viability and buildings, and a set of vehicle routes which are sequences of roads computed using Duarouter. The simulation stays running for a pre-specified number of seconds and runs along a TCP server, called TraCI, which provides external access to the simulation through a set of commands. Furthermore, SUMO is responsible for the microscopic simulation of vehicles and their mobility.

VeinS has been extended with the models of EVs and EVSE units (including the management of the EVs queues) and it has been integrated with the battery charging/discharging models described in [34]. In particular, OMNeT is used to characterize the electric vehicles through the simulation of the battery charging and discharging process, the charging stations and a reservation mechanism aiming to help the vehicles to schedule uniformly among the available charging stations. In OMNeT++ we implemented the module vehicle, which is correspondent to the vehicle running in SUMO, its electric battery and the driver's behavior. As an EV moves in SUMO, the model implemented in OMNeT++ calculates the corresponding discharge of the battery as a function of speed and acceleration and calculates the recharge of the battery when the EV is plugged to an EVSE.

Depending on the simulated time of the day, a different traffic rate is established (i.e. total number of vehicles running in the scenario at the same time). OmNET++ creates new vehicles through a command sent to the TraCI server and assigns to them the status of EV or gasoline-propelled vehicle (depending on a predefined parameter). When an EV reaches a level of battery lower than a pre-defined threshold it tries to go to recharge. This can happen either with or without the reservation policy already described in section V-B, which enables a significant decrease in recharge failures (e.g. too long waiting lines, full parking lots, etc.).

2) POWER DISTRIBUTION SYSTEM SIMULATOR

The Power distribution system simulator is based on electromagnetic transient program EMTP-rv. It is a time domain simulator, in which we have adopted a fine-grained time step of $\Delta t = 1ms$ in the simulations. The model of the distribution feeders includes the model of the three-phase unbalanced lines, three-phase HV/MV substation transformers equipped with an on-load tap changer (OLTC), and the models of the aggregated unbalanced loads (constant impedance / current / power) that includes the EVSE units.

The model of the EVSE aggregate is based on triplet of current sources, each controlled by a feed-back regulator in order to inject or absorb the requested per-phase values of active and reactive power, as described in [35] and [36]. Each aggregate load is connected at the secondary side of a MV/LV transformer. The EMTP model includes a DLL (Dynamic Link Library)-based interface that allows the communication with the SIB.

3) COMMUNICATION NETWORK SIMULATOR

The simulator of the UMTS communication network is based on the Riverbed Modeler Wireless suite. The Riverbed model includes the representation of the main components of the UMTS network: the user equipment (UE), i.e. the UMTS module of each agent, the Node B, the Radio Network Controller (RNC), which manages the Node B logical resources and the UE-Node B interface resources. The Serving GPRS support node (SGSN) maintains access controls, security functions and also keeps track of UE locations. Gateway GPRS support node (GGSN) encapsulates the packets and routes them to the SGSN that are received from the external network or Internet. The communication channels between each Node B and RNC are assumed wired with a large data rate.

The implemented model accounts for a block error rate (BLER), i.e. the percentage of transport blocks with errors over the total number of transport blocks. The Riverbed software supports the UMTS four main types of quality of service (QoS): background, interactive, streaming and conversational. These types of QoS are characterized by the traffic class, maximum and guaranteed bit rates, delivery order, transfer delay, maximum size of the service data unit (SDU) and SDU error ratio. The UE radio link control (RLC) interface could operate in either unacknowledged mode (UM) or acknowledged mode (AM), which includes retransmissions that decrease the effects of the BLER but increase the communication delay.

In the study described in this paper, the information exchanged between the agents uses the interactive QoS class communication that has higher priority than background QoS although, as background, it does not guarantee a bit rate. We have chosen to operate in AM.

In order to test the robustness of the control procedure against delays in the communication network, some simulations includes a background traffic (BT) created by additional UEs, other than those associated with the agents. These new UEs and also the agents, generate the BT by using some default mobile user traffic profiles defined by Riverbed Modeler according to the 3GPP technical report TR 36.822. Since the analysis of the scheduling effects of the chosen QoS is out of the scope of this paper, also the BT is assumed to use the interactive QoS.

B. MULTI AGENT SYSTEM FOR THE DISTRIBUTED CONTROL OF CHARGING STATIONS

Several studies have been recently presented in the literature that analyze the foreseen impact of plug-in electrical vehicle charging on the electric power network, and present different approaches in order to limit the negative effects and optimize the operating conditions of the system (e.g. [7], [37]–[46], and references therein). In this paper we focus on parking lots that include fast public charging stations with power rating assumed equal to 50 kW. The EVSE units of each parking lot are fed through a MV/LV transformer. Following the hierarchical aggregation approach adopted in e.g. [40]–[42], we analyze a multi-agent system that is composed by the intelligent electronic devices (IEDs) installed at the HV/MV substation and in correspondence of critical branches of the network that may be overloaded due to EVs charging and by distributed agents, i.e. control units connected to the shared communication network, each associated to the cluster of EVSE units of a parking lot. The implemented distributed control algorithm allows the congestion management of the network whilst a local regulation function of the agents reduces the charging effects on voltage variations. Each agent communicates also with each single EVSE of the cluster in order to allocate the maximum power that could be absorbed from the MV network among the various charging EVs taking into account their specific characteristics and requirements. In this paper we assume that the multi-agent system (MAS) uses a third generation mobile cellular network, namely a Universal Mobile Telecommunication System (UMTS).

1) ALGORITHM

Each IED is able to communicate an index over the UMTS cellular network that denotes whether and how much the corresponding power component is overloaded. In the literature this type of indexes are often called congestion prices (e.g., [38], [40]). The agent associated with each cluster of EVSEs is able to control the charging power according to the received congestion index. The procedure implemented in the simulator is the following. For illustrative purposes, we assume that at time t, IED_j associated to the first branch of feeder j detects an overcurrent condition, i.e.

$$e_{j,t} = \frac{i_{j,t} - i_{j,\max}}{i_{j,\max}} \qquad (2)$$

greater than 1 where $i_{j,t}$ is the measured rms value of the current at time t and $i_{j,\max}$ is the maximum operating value. Then IED_j calculates the variation of the congestion index Δpr_j as

$$\Delta pr_{j,t} = K_c\left[\left(e_{j,t} - e_{j,t-1}\right) + \frac{\Delta t}{\tau_I}\left(\frac{e_{j,t} + ej,t-1}{2}\right)\right] \qquad (3)$$

where Kc and I are constants, which are chosen equal to 0.2 and 0.1, respectively, in the simulations. Equation corresponds to the velocity algorithm of a digital PI controller. Through the communication network, value $\Delta pr_{j,t}$ is sent by IED_j to the agents associated to clusters of EVSE units connected to feeder j. IED_j continues to perform calculation until $\Delta pr_{j,t}$ becomes and stays constantly small enough for at least a predefined settling time T_{set} chosen equal to 10 seconds. After T_{set}, $\Delta pr_{j,t}$ is set equal to 0. With a selected time step Δt (chosen equal to 1 s or 3 s in the simulations), the updated value of $\Delta pr_{j,t}$ is sent to the agents. Each agent i that receives $\Delta pr_{j,t}$ at time t updates its own congestion index as

$$pr_{i,t} = \max\left(1, pr_{i,t-1} + \Delta pr_{j,t}\right) \tag{4}$$

and fixes the maximum power that could be absorbed by the relevant cluster of EVSEs as

$$P_{EVSE_{i,t}} = \frac{\hat{P}_{EVSE_{i,t}}}{pr_{i,t}} \tag{5}$$

where $\hat{P}_{EVSE_{i,t}}$ is the maximum power requested by the EVSEs of the cluster associated to agent i at time t. Compared with the broadcast of congestion indexes, the velocity form of the control mechanism provided by (3) avoids reset windup and, in (4), it permits to sum the contributions of various IEDs that detect the concurrent overload of different power components. Each agent i also includes a local voltage regulator that proportionally reduces if the local voltage at the MV side of the transformer is lower than a predefined value (e.g., 0.97 pu).

2) SIMULATION RESULTS

A sector of the city center of Bologna has been used as a testing scenario in which entities are deployed as shown in fig. 7. The figure indicates two 15 kV feeders fed by 132/15 kV substation SB_A and the locations of four parking lots each assumed to be equipped with ten 50kW EVSE units, denoted as EVSE_1 and EVSE_2, EVSE_3 and EVS_4. The first two clusters of EVSEs are connected to feeder 1, whilst the second two are connected to feeder 2. Figure 7 also shows the main components of the implemented model of the UMTS communication network, assuming that all the four agents each associated to a cluster are served by the same Node B.

The traffic simulator generates a flow of random events. Each event represents a specific trip of a vehicle in the city from a starting point to a destination. For the case of EVs, when the SoC of the corresponding battery is below a threshold set to 25%, the vehicle deviates from the planned journey and reaches the closest EVSE unit available.

The EMTP model represents the two 15 kV feeders of interests with the relevant loads, the 132/15 kV transformer of the HV/MV substation and the equivalent impedance of the HV network. It includes also the model of three-phase loads (assumed constant for these simulations) and the aggregate EVSE models of clusters EVSE_1, EVSE_2, EVSE_3,

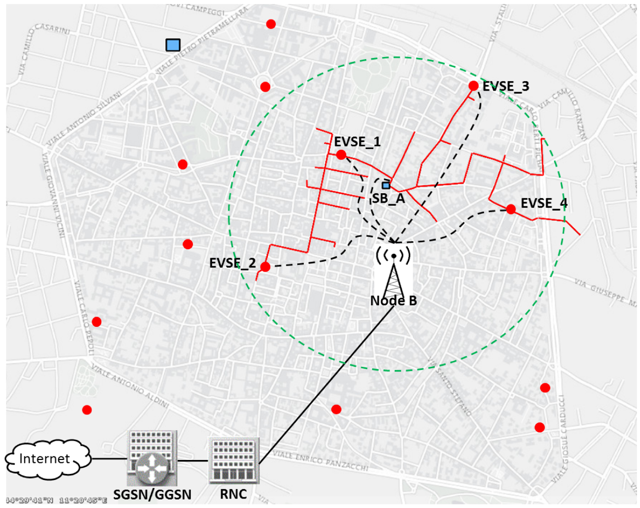


FIGURE 7. Top view of the map of Bologna with the indication of parking lots with GCPs or EVSE clusters (red dots), of HV/MV substations (blue rectangles), the analyzed two 15kV feeders and the model of the UMTS communication network (dotted black lines represent wireless channels, solid black lines represent wired channel). The green circle indicates the estimated coverage areas of the Node B antenna.

and EVSE_4, each fed through a 15/0.4 kV transformer. Moreover the EMTP model represents both the IEDs and the agents that communicate between each other and the SIB through the DLL interface.

The results presented here refer to a simulation that starts with a random generation of 200 events, each one every 5 seconds. With a 50% uniform probability each event is associated with an EV, otherwise is represented by a fuel vehicle. Every time a vehicle leaves the simulation, i.e. reaches its destination, a new event is generated. For illustrative purpose, the EVs are generated with a SoC below the minimum threshold.

EMTP is linked and synchronized with VeinS after 400 s of traffic generation.

The simulations are repeated for two different BLER values: 1E-5 (case indicated as BLER0) and 0.1 (BLER1), which is a typical reference performance value (e.g. [47]). Moreover the same simulations are repeated with the BT (case indicated as BT1) and without the BT (BT0). BT is generated by the UEs associated to the agents and by seven additional UEs and two traffic receivers. The two adopted mobile users application models are characterized by two different gamma distributions of the inter-arrival packet time in s (with parameters 0.0068, 5 and 0.2, 0.5, respectively) and exponential distributions of packet size in bytes (with parameters 41.03 and 62.97, respectively).

Figure 8 shows the dynamic change of the number of vehicles that are connected to an EVSE of each of the four considered clusters, whilst fig. 9 and fig. 10 show the requested power by each of the clusters and the current measured at the beginning of the two feeders. The current value of 1 pu indicates the maximum allowed operating value (in the considered feeders it is equal to 200 A).

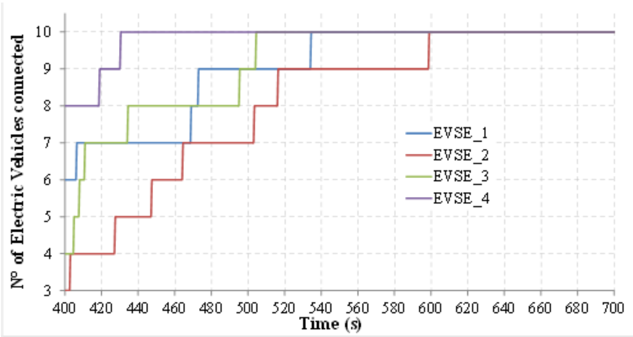


FIGURE 8. Power requested by each EVSE cluster ($\Delta t = 1s$).

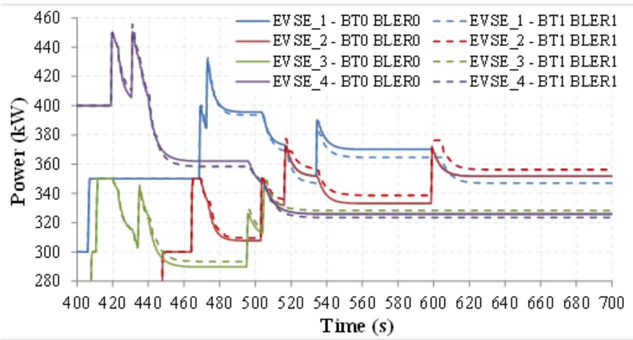


FIGURE 9. Current value measured by the IEDs associate to the first branch of the two considered feeders ($\Delta t = 1s$).

As shown by fig. 9, after 420 s the IEDs associated to the initial branch of the two feeders detect an overcurrent condition. They calculate the variation of the congestion indexes according to and send them at each $\Delta t = 1s$ to the agents of the relevant EVSE clusters. The sent values of the congestion index variations and each agent update its congestion index value independently. The congestion index is used by the agents in order to limit the EVSE power according to (5). Figure 9 shows the limitation of the absorbed power by each EVSE cluster, whilst fig. 10 shows the effectiveness of the control action that is able to promptly compensate the overloading conditions caused by each new connection of an EV to an EVSE.

As shown by fig. 8 and 10, without communication interference and packet loss, the final power requested and congestion index by the clusters connected to the same feeder is equal. With delay and loss of information, this fairness condition is no longer verified and these values differ from each other by 9.3 kW for EVSE_1 and EVSE_2 (feeder 1) and by 4.8 kW for the EVSE_3 and EVSE_4 (feeder 2).

The simulations have been repeated for $\Delta t = 3s$ with analogous results. In order to compare the performances for the various cases, Table 1 shows: the total overloading duration during which the currents measured by the two IEDs, indicated as I_1 and I_2, exceed the maximum value, the maximum current measured by each IEDs, the mean and standard deviation of the delay of the communication packets and the correspondent number of packet transmitted

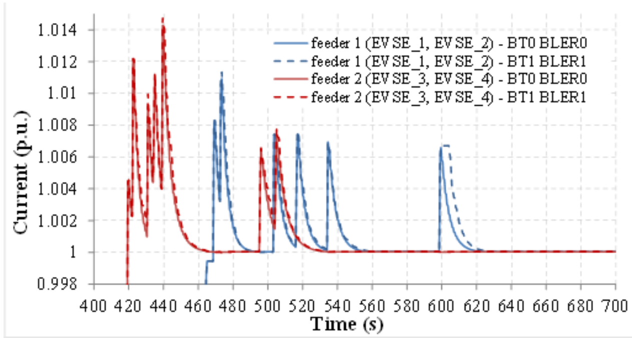


FIGURE 10. Current value measured by the IEDs associate to the first branch of the two considered feeders ($\Delta t = 1s$).

TABLE 1. Time above the current limit, packet delay and number of packets (Tx: transmitted, Rx: received).

BT BLER	Time $I_1 > 1pu$ (s)	Time $I_2 > 1pu$ (s)	I_1 max (p.u.)	I_2 max (p.u.)	Packet Delay (ms) mean (stdev)	Number of packets TX RX
BT0 BLER0 $\Delta t = 1s$	93	79	1.0109	1.0143	142.6 (10.0)	378 378
BT1 BLER1 $\Delta t = 1s$	101	81	1.0113	1.0147	231.3 (189.0)	406 363
BT0 BLER0 $\Delta t = 3s$	71	69	1.0107	1.0149	149.7 (12.7)	122 122
BT1 BLER1 $\Delta t = 3s$	81	69	1.0107	1.0149	235.3 (180.5)	128 120

and received. As expected, for the case of communication affected by BLER and BT, both the mean value and standard deviation of packet delays are larger than in the case of ideal communication. Moreover BLER causes the loss of some packets. The use of $\Delta t = 3s$ limits the number of packets and reduces the influence of both packet delay and packet loss. The overall performance of the implemented control strategy is not significantly affected by the presence of BLER and BT. The difference between the results obtained for $\Delta t = 1$ s and $\Delta t = 3s$ is not significant.

C. ANALYSIS OF THE POWER FLOW PROFILES IN THE DISTRIBUTION NETWORK

The aim is at calculating the expected power flows in the power distribution network in different hours of the day in different operating conditions. The model includes the representation of an ideal congestion management strategy. We present here the illustrative results of a daily simulation run. Both for the vehicle generation and for the profile of ordinary city loads we used realistic profiles. Figure 11 shows the profile of city loads, sampled each 15 minutes, for a typical weekday.

Figure 12 shows the average distribution of the traffic in the urban area of Bologna during a day. The number of vehicles in the simulation at each time step is controlled in order to follow this distribution. Each simulation can be run with different parameters regarding the percentage of electric vehicles (which establishes both the probability of generating an electric vehicle and the maximum number of electric vehicles running at the same time) and the number of

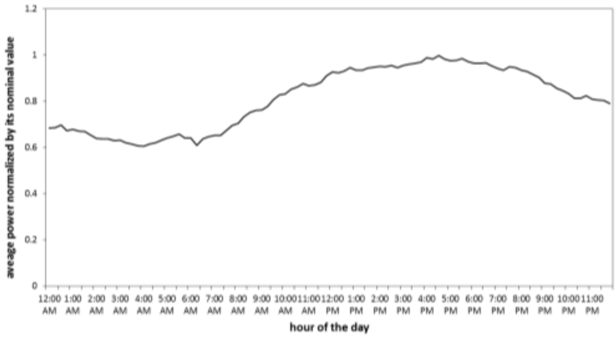


FIGURE 11. **Graph representing the average power drained by a city load during a typical weekday.**

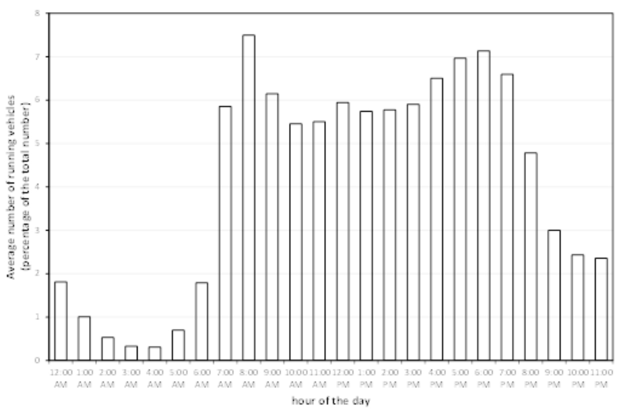


FIGURE 12. **Distribution of vehicle traffic during the day.**

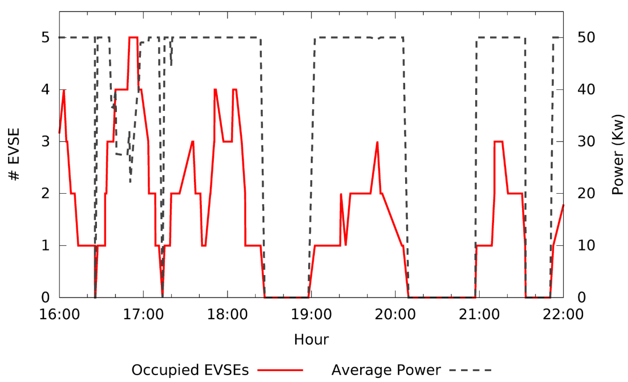


FIGURE 13. **Portion of a simulation run showing the average power absorbed by the EVSEs downstream to IED 2 over a span of about 6 hours and the number of occupied EVSEs.**

vehicles running through Bologna in a whole day. The results of this nection refer to the case of 30000 vehicles running per day with 4% of electric vehicles.

Figure 13 and 14 show the results of the same simulation. Both the number of occupied EVSEs and the average power per EVSE are shown. The results refer to the EVSEs connected to the GCPs downstream IED2. Figure 13 shows that the average power available to the occupied EVSEs is nearly always 50 kW apart from a time lapse,

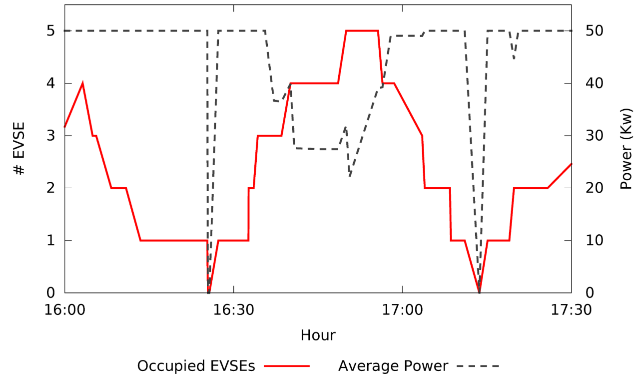


FIGURE 14. **Particular of the simulation showing the point of interest.**

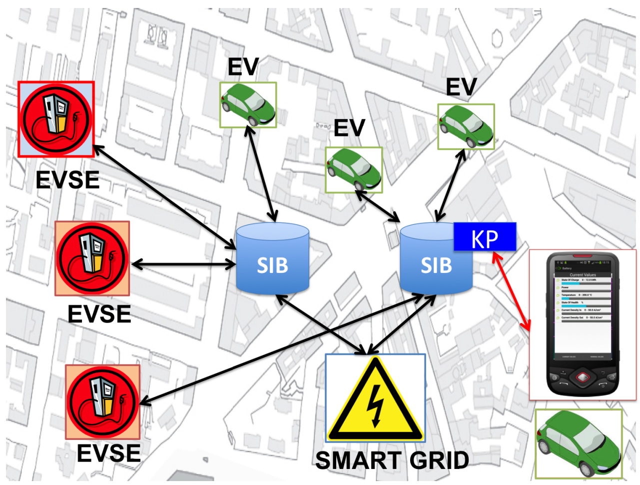


FIGURE 15. **Architecture of the service platform for EV mobility scenarios.**

from about 4:30 PM to 5:15 PM, in which the power demand is high both from the EVSEs and from the other loads in the city. Figure 14 provides a more detailed analysis of such a time lapse.

V. SERVICE PLATFORM

A. SERVICE ARCHITECTURE

In the context of SG, in particular when referring to Electro Mobility, the world of mobile, in-vehicle and context aware services has a fundamental role: simplifying the transition to the new infrastructure by both reducing the impact on the end users, who feel anxious to use new technologies, and also encourage the transition to EVs. Another possible source of disconfort is the need or the will to recharge an EV but without knowing if the near charging spots are busy. For these and other kind of simplification of EV user's life we propose a service infrastructure strictly coupled with the information management and communication framework described in section III, as well as with the co-simulation framework described in section IV. Our proposed service architecture is shown in Figure 15. We consider realistic EV scenarios, characterized by the heterogeneity of the actors involved on them; i.e. different EV models, EVSEs providers and smart-grid operators, each using their data representation techniques, and providing their own services, mobile applications, or APIs for third-party software deployment. In such a chaotic environment, our goal has been to devise an highly general framework for the deployment of interoperable mobile services, providing all the main functionalities requested by EV drivers and discussed in Section II, i.e.: profiling, route planning and charging reservation. In the architecture of Figure 15, data interoperability is achieved through a semantic approach, i.e. the utilization of a shared ontology among all the actors of the scenario. The power-grid ontology better detailed in [34] allows defining all the physical entities (i) (e.g. Vehicle, EVSE, Connector), (ii) abstract entities (e.g. Data, ChargeProfile) and (iii) service specific terminology (e.g. ChargeRequest, ChargeResponse, Reservation, and so on). All data produced by the scenario actors are then collected through SIBs [48]. Note that this approach does not imply the replacement of existing management systems (e.g. used by a specific EVSE provider), but only the data translation from proprietary formats into the semantic ontology domain, through the utilization of proper communication interface to/from the SIB. The KPs interacting with the knowledge base during the service provision are then developed according to the principles of separation of concern and service composition; they allow mining the SIB data, and can be easily integrated one with each other in order to allow the definition of novel mobile services for EV drivers. In the following, we detail three examples of mobile services deployed so far, on top of the architecture of Figure 15.

B. THE RESERVATION SERVICE

In this section we describe the reservation service [49], [50]. Driven by the longer recharge times needed for the Electro Mobility, compared to the time needed by refueling, we developed a reservation service to help reducing the waiting times before plugging the vehicle, that might happen in case the EVSE is occupied when the driver arrives there.

When the EV drivers need a recharge, instead of driving directly to the closest EVSE, they look for an available charging opportunity in the SIB, by asking for the available EVSEs in a target area, and during a preferred time frame.

The SIB will then reply to the user with a list of EVSEs that satisfies the input query. The user has to select one of them, based on current position, EVSE delivered power, and EVSE position, which indicates also the amount of deviation from the original path. The reservation is complete when the user replies with the desired choice, and the SIB acknowledges it.

In Figure 16 we show a screenshot of the mobile application client using the reservation service. In the first Figure, we include a screenshot showing the result of a user query, and including all the EVSE that match the user preferences. Then, a user selects the preferred EVSE, along with the time at which the reservation has to be made. The application eventually shows the path from the position of the user to the destination, and the time at which the reservation is made.

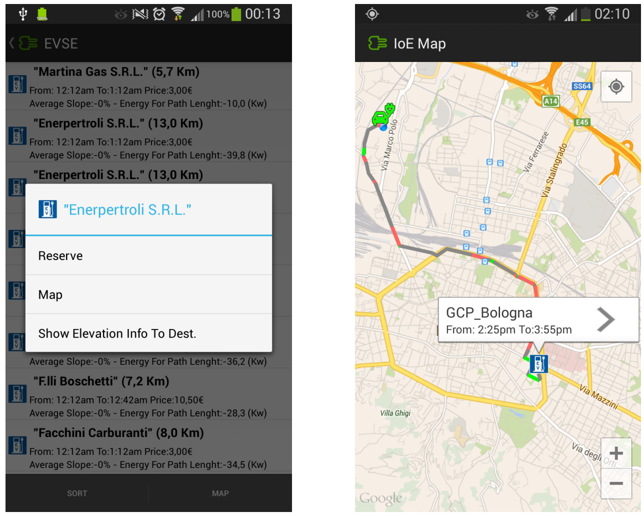


FIGURE 16. The reservation service.

This is also computed by taking into account the traffic through the path, thanks to the Google Directions API.

C. THE ROUTE PLANNING SERVICE

In this section we describe the route planner service, which is depicted in Figure 17 [51]. One of the most relevant issue of Electro Mobility is the uncertainty of successfully travelling through a planned trip. This issue derives from the complexity of estimating the consumption along the path in an accurate way, as well as from the low density of charging opportunities. Hence, we built a tool to assist the electric driver,

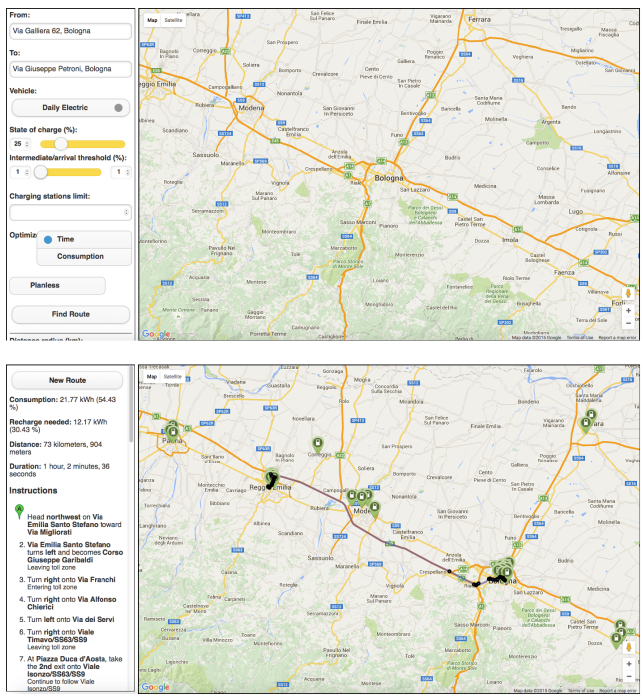


FIGURE 17. The route planning service.

by computing the expected consumption over the desired path, and identifying the needed charging opportunities by minimizing either the total travel time or the total consumption.

The route planner works as follows. First, we compute the expected consumption between the start and the end of the path. If it satisfies a user defined threshold of intermediate charge, the system simply returns the desired path with the directions to reach the destination. We introduce this threshold, called Intermediate State Of Charge (SOCint), as a safety threshold that users can tune based on their anxiety.

If the path is not feasible, because it violates the SOCint parameter, we then search for an available charging spot, by minimizing the deviation needed from the original path. We look for EVSE closer to the destination compared to the starting point, to avoid the problem of looking for a charging opportunity farther and ending up in a longer trip. From each EVSE which can be reached without violating the SOCint threshold, we look at all the paths from each EVSE to the destination, if feasible. If we find one which does not exceed the SOCint parameter, we look for a feasible path from the EVSE to the destination. Among all the feasible paths, we take the one that either minimizes the consumption or the travel time, according to the user preference. If we cannot find a path with the previous step, we then execute again the algorithm to find an additional EVSE in which we can charge starting from the previous EVSE, which becomes the starting point for the next step. We continue with this algorithm until either we find a feasible path, and we return it to the user, or we cannot find any, and thus we return to the user telling that it is not possible to travel through the desired path with the chosen parameters.

D. THE WHAT-IF SERVICE

In this section we describe the What If Application, developed to encourage fossil fuel vehicle drivers to consider Electric Vehicles [52]. The main purpose is in fact the ability to record the usual trips a user covers during the day, and simulate what would happen if the same trips have to be covered with an electric vehicle. In Figure 18 we show three screenshots of the application. It is composed by two main functionalities, record and simulate. The record feature allows to keep track of the journey made while driving, and record it for later use. The simulate feature instead takes as input a recorded path and simulate it by using different electrical vehicles. To allow for more flexibility, we also provide the option to build a path off-lline, defining starting, intermediate, and ending points. This is helpful also to simulate possible trips without the need to actually cover them with a vehicles. Trips can be bind together to form journeys, by adding stops between them. Planned stops, can then be used to leverage charging opportunities.and, from the perspective of SG operators, to plan and deploy new charging stations in hotspots where people usually leave the car. As output of the simulation, the user can understand how much he/she would need to deviate from their preferred and planned path when using an electric vehicle.

E. SERVICE EVALUATION, METHODOLOGIES AND RESULTS

One of the main limitations of the existing mobile applications for EV-related scenarios is the lack of adequate validation/evaluation results clarifying the effectiveness of such services over realistic EV scenarios. Evaluation of mobile services is a challenging task, due to the cost of setting up large-scale test-beds, and the lack of adequate simulation tools. In the IoE project, we have addressed such issue thanks to innovative immersive emulation techniques, whose details can be found in [50]. Shortly, we provide solutions to embed mobile applications into the co-simulation framework described in section IV, which already includes realistic modeling of vehicular mobility, of EV battery discharging, and of power-grid dynamics. This is made possible by the component called Mobile Application Zoo (MAZ) in Figure 19, which provides bidirectional connectivity between a mobile application and the co-simulation platform. Communication is implemented through data exchange facilities between the application, the simulator and the SIB. It is worth highlighting that the embedding process does not require any change to the mobile applications, which are completely unaware of being

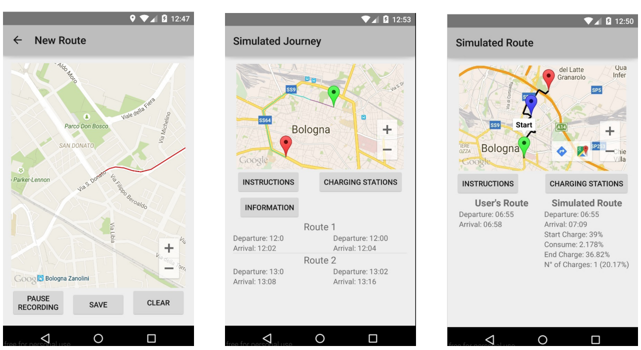


FIGURE 18. The What-If service.

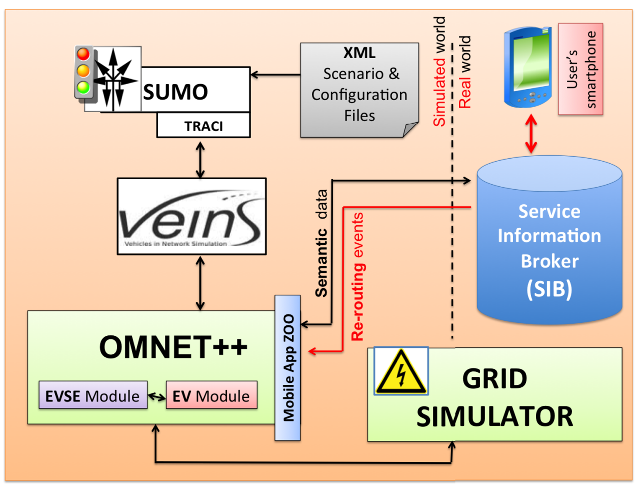


FIGURE 19. The embedding of mobile applications within the co-simulator environment described in section IV.

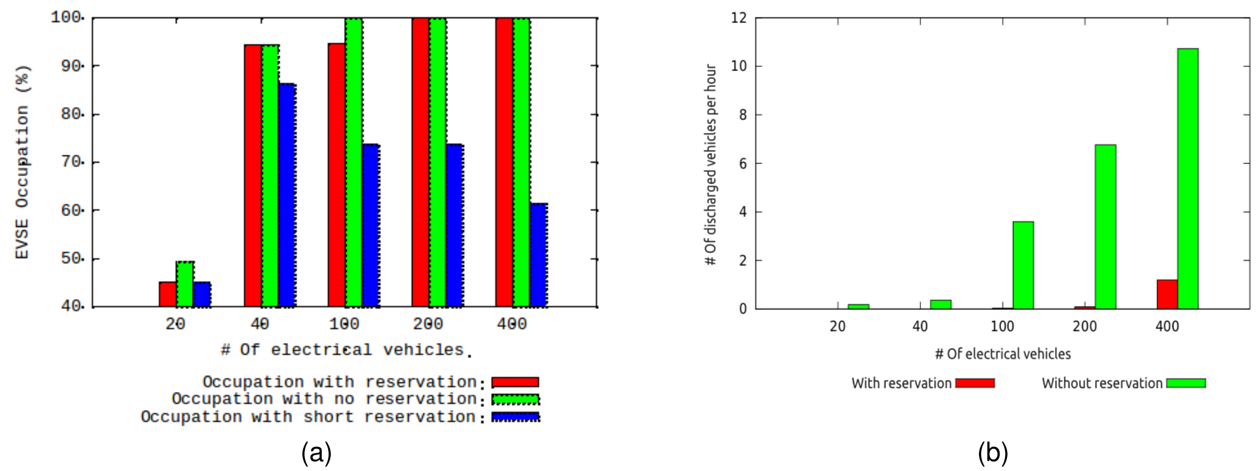


FIGURE 20. Evaluation of mobile services for EVs: EVSE occupation for reservation service (*a* and *b*).

processing synthetic data. As a result, a mobile application will be able to retrieve and display data of a simulated vehicle (e.g. current charge state), as if the users were driving it. Vice versa, interacting with the mobile application, the user might perform actions that trigger events within the simulation: for instance, when performing a reservation through the mobile application of section V-B, an event is generated, in order to re-route the simulated EV toward the selected EVSE. The MAZ component provides two main advantages. First, it allows testing the correct behavior of mobile applications under several different conditions that might occur on a real-world scenario. Second, it allows evaluating the performance gain provided by the utilization of the mobile applications described in sections V-B, V-C and V-D when all the scenario components are in the loop, i.e. the vehicular traffic, the charging/discharging operations, the impact on the smart-grid. We are not aware of other existing simulation tools for EV-related scenarios, providing such level of modeling details. In Figures 20 and 21 we provide examples of performance analysis that can be performed through the mobile services embedding technique.

More specifically, Figure 20(a) depicts the average EVSE utilization when using or not the reservation service described in section V-B. In case reservation is not used, the simulated EV performs a traditional EVSE seeking policy, i.e. they drive from an EVSE to another, till an available one is found. The reference scenario is the downtown area of Bologna, Italy, considering real EVSE positions (imported by PlugShare services), and 3D street maps (imported by OpenStreetMap). Figure 20(a) shows that the average occupation decreases while increasing the number of charging stations available in the scenario. The average occupation without reservation is generally higher than with reservation because simulated EVs fastly fill all the available charging spot in an uncoordinated manner. However, if we look at figure 20(b), we can notice that the number of EVs that runs out of battery without being able to recharge, is much larger when reservation is

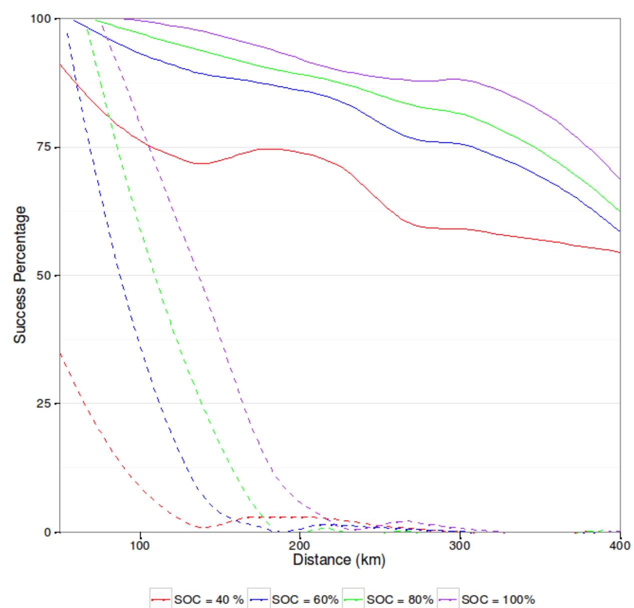


FIGURE 21. Success probability for the route planning service.

not present. This happens because when all the charging spots are filled the residual EVs being unaware of the situation, continue to travel until the residual charge ends. In the simulations with an active reservation service, instead, vehicles wait near the reserved EVSE for their reservation time to come. These two results provide two important indications, in terms of service and infrastructure deployment. On the one hand, they clarify the usefulness of our reservation service, since it guarantees a more uniform utilization of the EVSEs of the Bologna scenario, which translates into much efficient scheduling of charging operations. On the other hand, they complement the analysis described in section IV, since they provide feedbacks about the optimal planning of the charging infrastructure, in terms of number of EVSEs. Similar considerations can also be derived by figure 21, where we evaluated the effectiveness of the route planning service. Here, we simulated a large-scale scenario, i.e. the Italian Emilia-Romagna region, taking into account real EVSE positions and 3D street maps. We generated random trips within the scenario, and we studied the Success Probability (SP), i.e. the probability to reach the destination, when following the indications of the route planning service described in section V-C or when using a conventional approach commonly adopted by EV drivers. This approach consists in following the shortest path, and in seeking for an available EVSE, only when the charge is below a given threshold. Figure 21 shows that the SP decreases (dashed lines) without route planning but also decreases, in a slower way, with route planning. This happens because the coverage of EVSEs on the target scenario is not uniform: most of the EVSEs are located on urban areas, while charging opportunities are quite scarce in rural areas. However, as before, figure 21 provides useful feedbacks for the service planning, since it demonstrates the performance gain of a planning service for medium and long trips, and for the grid planning, since it allows detecting the areas of the Emilia Romagna which are mostly uncovered by the current charging infrastructure. The last described results are examples of the quality of the results achievable when different research groups focusing in different areas (i.e. mobile services, power network simulation, vehicular simulation, and information representation techniques) cooperate on a single scenario.

VI. LESSONS LEARNED ABOUT ICT INFRASTRUCTURES FOR LARGE-SCALE AND INTEROPERABLE SMART GRIDS

Nowadays it is common to see two important area of research in the same contexts: the SG and the IoT. This happens because many scenarios originated by the SG, with high number of interconnected nodes providing observations and requiring commands, are clearly addressed by the IoT infrastructure. This section is about our work in the field of IoT to design components at middleware level which supports the IoT requirements and that can be deployed in industrially relevant SG scenarios. This work can be seen as horizontal with respect to all the aspects and services presented in this research work because the final objective is to enhance the technology readiness level of the whole infrastructure making it ready for the final deployment on the cloud infrastructure whose plan will be detailed in section VII. The main challenge faced is the heterogeneity of the components to be interfaced that is imposed by legacy motivations. Obtaining a prototype of an IoT infrastructure supporting the SG, in order to improve the technology readiness level, is also one of the objectives of the European project Arrowhead which is currently ongoing and that is one of the principal carriers of the authors collaboration at moment.

The recent popularity of the IoT across multiple domains has stemmed from the diffusion of networking-enabled consumer devices that are deployed on a geographically wide-scale. We have worked and are working to address wide-scale deployment scenarios of IoT and for the near future of SG and Electro Mobility, where a large fraction of vehicular traffic will consist of electric vehicles. These scenarios give rise many technical and organizational challenges - from the monitoring of current road traffic to the optimization of travel paths based on recharging availability; from the localization of target vehicles to the dissemination of alert message in an audio or text format; from the identification of spatio-temporal recharging patterns for enabling mass scale user behavior prediction, to the optimization of smart grid management in order to adequately sustain the expected patterns of recharging requests from different geographical areas.

Real world IoT deployments are fundamentally heterogeneous; they are often derived from the integration of already independently deployed IoT sub-networks, characterized by very heterogeneous devices and connectivity capabilities. Potential networks in the smart transportation cases may include single-hop wireless communications based primarily on Near Field Communications and ZigBee between neighboring cars and between cars and recharging sites, while single/multi-hop WiFiDirect and IEEE 802.11p communications will enable the dissemination of useful recharging data among moving vehicles, as well as of user-generated entertainment content flow (e.g., tele audio or video streaming flows) between cars. In addition, 4G-based access to the standard Internet infrastructure will enable real-time collection of monitoring data at datacenters either directly from cars (often through smartphone-based gateways) or via intermediary collectors at road side units.

The heterogeneous network and device resources create opportunities for a wide range of applications (semantic tasks) with varying service requirements to execute concurrently. The envisioned classes of tasks may include: 1) simple point-to-point client-server applications that require real-time, dependable, and high quality message exchange - e.g., real time information about the road/vehicle status from end devices (highway camera or vehicle) to the data center. Such applications require low latencies and reliable delivery of information; 2) monitoring applications that collect data periodically from a multitude of data sources, such as in the case of recharging sites, monitoring for global state awareness and optimization. A sample query might be "get availability of recharging sites and traffic statistics on vehicles that have been charged there". In this case, there is no strict requirement on latency and on message loss, but a relatively significant number of updates from traffic, often generated in a very asymmetric way; 3) opportunistic exchange of local monitoring/personal data, especially between moving vehicles or between vehicles and Internet access points on the way, e.g., "audio chat among cars in a fleet". In this case, due to the interactions between multiple parties, a lower jitter is required, while throughput might be less important.

While opportunities for new classes of applications are created in this heterogeneous setting, new challenges are introduced. The first issue involves shared provisioning of network and sensor resources across applications for efficiency. In the heterogeneous IoT setting, different user-defined tasks may run simultaneously with differentiated quality requirements in terms of reliability (packet loss), latency, jitter, and bandwidth, thus optimizing sharing of sensing and communication resources and coordinating messaging in this context is challenging. The second issue is an interoperability challenge that arises when heterogeneous devices exploit different data formats for modeling information and diverse protocols for M2M data exchange. The varying throughput, latency, and jitter requirements of applications' enhance the complexity of state capture and resource provisioning. For instance, monitoring data between neighboring cars and a recharging site or between a recharging site and the smart grid infrastructure is often transmitted nowadays by adopting the relatively efficient M2M protocol called MQ Telemetry Transport (MQTT). However, our experience with interoperability challenges and the service orientation principle discussed above push towards considering, at least in some cases, open and flexible protocols (even if format-inefficient and expensive), such as eXtensible Messaging and Presence Protocol (XMPP) for message exchange between cars and between a car user and a user-oriented service implemented over the support infrastructure, e.g., the recharging sites booking service.

For all the above motivations, we have decided to design and implement a novel software stack enabling effective resource provisioning in IoT Multinetworks environments, to accomplish heterogeneous IoT tasks with the requirements imposed by the incoming SG scenarios. As a step towards this ambitious goal, we have developed MINA, a reflective self-observing and adapting middleware exploiting the Observe-Analyze-Adapt loop, to realize and manage dynamic and heterogeneous multi-networks in pervasive environments [27]. In particular, MINA achieves a reasonably accurate, centralized global view of the currently available multi-network environment and takes advantage of this global view for adapting it, e.g., by reallocating application flows across paths. More importantly, MINA adopts state-of-the-art Software-Defined Networking (SDN) technologies to achieve flexible resource matching and efficient flow control in industrial deployment environments. To this purpose, we propose a novel IoT multinetwork controller, based on a layered architecture, that makes easier to flexibly and dynamically exploit IoT networking capabilities for different tasks described by abstract semantics. Moreover, we propose a genetic algorithm to optimize its exploitation through differentiated dynamic management of heterogeneous application flows.

As a further example of the benefits of inter-disciplinarity in this field, here we overview our novel SDN-oriented IoT Multinetworks controller architecture that puts together expertise and optimization goals from network management, SOA middleware, vehicular networking, opportunistic networking, and QoS requirements of smart grids and intelligent transportation systems. As shown in fig. 22, the data

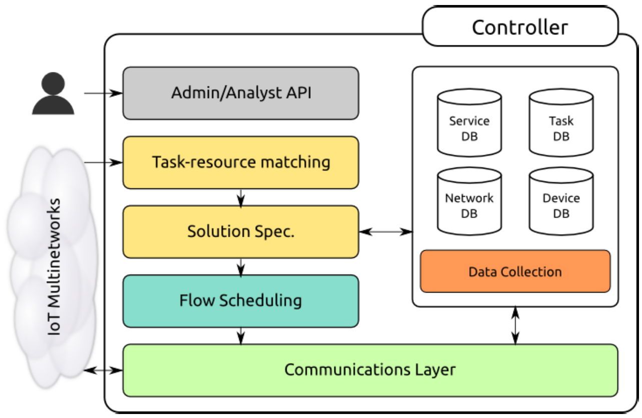


FIGURE 22. IoT controller architecture.

collection component collects network/device information from the IoT Multinetworks environment and stores it into databases. This information is then utilized by the layered components in the left side. The controller also exposes the Admin/Analyst APIs, which enable the control processes to be governed not only by the controller itself but also by humans or external programs. Note that while the controller is logically centralized, to improve scalability it can be instantiated multiple times in different locations, e.g., in a per-domain per-service way.

We argued that the concept of SOA and of proper abstraction levels for reusability and interoperability is fundamental to our vision of IoT Multinetworks since it allows to make use of multinetwork resources in a flexible manner. As shown in fig. 23, tasks are the highest level of abstractions in IoT Multinetworks that define what is required; this leaves open the choice of what applications/services, devices and communication networks should be exploited to accomplish the required task. A simple example might be to determine how many vehicles currently there are in a recharging station. Services are concrete software/hardware entities that help in the realization of a task. A task may be realized by a single service (capture video from recharging station) or a workflow of services that together realize the task (capture video and count vehicles). A task/service mapping specifies which devices and applications should be used to complete the task. The lower level Flow and Network layers decide

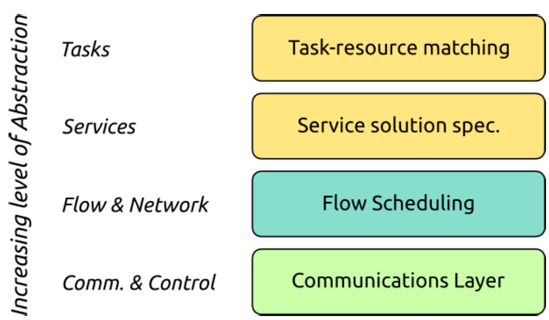


FIGURE 23. Layering in the IoT controller.

which networks should be used for application flows and how application flows should be routed across the network. These decisions will be sent out to the corresponding devices via the communication and control layer.

Such a layered view has benefits since it hides the details of lower layers (network/devices) so that tasks can be accomplished in a more flexible way. Furthermore, the separate abstraction levels allow dedicated algorithms to be designated to a certain layer for improved performance. Once a task is submitted to the controller from a requesting node, the controller components process it through a series of steps:

1) The task-resource matching component of the controller maps the task request onto the existing resources in the multinetwork. Then, it will filter out resources from this set by checking whether they have (and are expected to have in the provisioning time window) the requested QoS capabilities. The information about the various capabilities of resources and what services they provide are stored in our interoperable SIB. The result of the task-resource matching component is a list of compatible resource sets, which are then refined by the task-resource matching component through determination of proper settings. The deriving instantiated resource solutions are then filtered by automated policies at the controller or via a human in the loop (i.e., a network operator);
2) Once a solution is selected, the service solution specification component of the controller maps the characteristics of the devices and services involved in that solution to specific requirements for devices, networks, and application constraints (e.g., minimum throughput). For example, the solution that uses a road camera to locate and track vehicles will imply certain data rate and delay requirements of the video surveillance service, given the video frame resolution, codec, and receiver's buffer;
3) The Flow Scheduling component takes these requirements and schedules SDN flows that satisfy them. Scheduling and coordination of the resources in IoT Multinetworks are complex due to the heterogeneity of the networks and various QoS requirements of flows. We propose to use a logically centralized management and coordination component (the flow scheduling algorithm is described in detail in [27];
4) Finally the controller triggers the necessary communications in the IoT Multinetworks, e.g., a SDN command like "routing the video data sent from Camera 001 via Ethernet" will be sent to the devices along the path.

We have implemented a prototype of the proposed controller by integrating the co-simulation framework with OpenFlow-like protocols, thus again showing the need for inter-disciplinarity in the field. For the sake of briefness and simplicity, the performance results reported in the following refer to scenarios where only one node serves as the controller and the remaining nodes are all controlled devices.

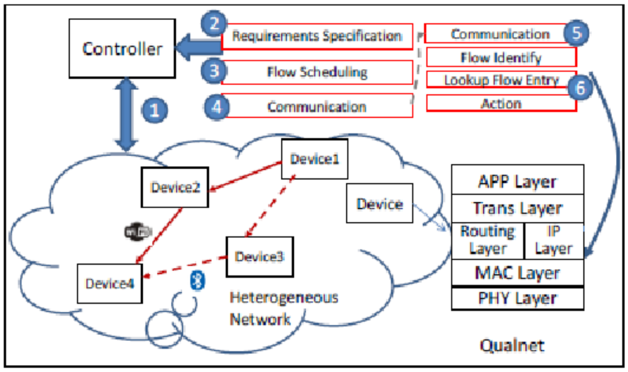
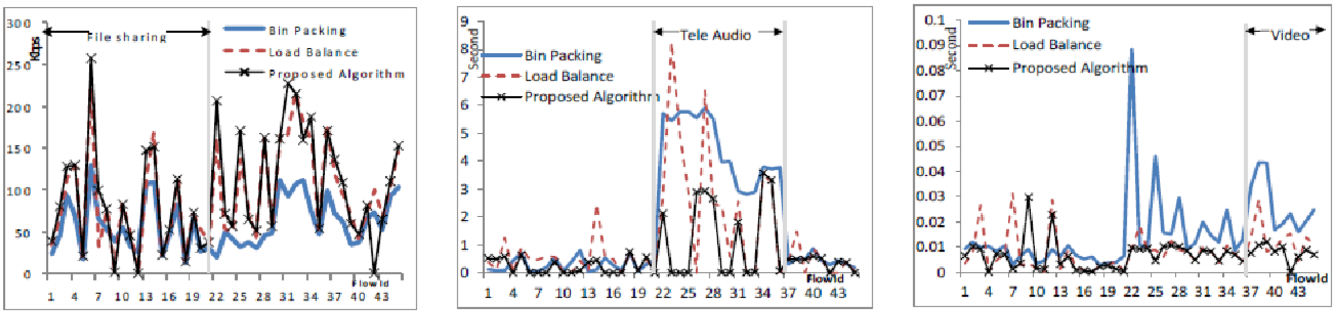


FIGURE 24. **Operational flow diagram.**

In fig. 24, we illustrate the operation flow of how this protocol works in an SDN way:

1) service or application requirements, network topology, and device properties are registered to the controller and stored in the SIB;
2) the controller translates service requirements into network QoS requirements. Preprocessing and analysis is performed if necessary;
3) the controller exploits an original genetic-oriented algorithm [27] for multi-constraints flow scheduling in order to fulfill QoS requirements;
4) the controller sends flow entries to controlled devices in charge of routing flows. A flow entry contains information such as source/destination IP address/port, IP address of next hop, and the new destination IP address;
5) controlled devices receive flow entries from the controller;
6) controlled devices identify each flow going through (by source/destination IP address/port), and check whether there is an entry for this flow, then do actions determined by IP address of next hop and the new destination IP address.

Among the series of performance results collected, here we report the evaluation of our genetic flow scheduling while comparing it with other two common scheduling algorithms used in SDN world: bin packing and load balance. The former tries to maximize the link utilization, which means it tries to accommodate as many flows as possible into a single link. Instead, the latter assigns flows into a link so that the total amount of the flows are proportional to the capacity of the link. Details about the exploited topology and the network characteristics can be found in [27]; each participating device has three network interfaces, at each time instance only one interface can be used; however, vertical handover could be performed if necessary; 3 data servers are employed to provide either file sharing, tele audio, or video streaming services. We assign each of the 45 end devices a service, randomly chosen from 16 file sharing services, 11 tele audio services, and 7 video streaming services. File sharing flows are modeled by sending Constant Bit Rate with packet length uniformly distributed in [100, 1000] bytes with period T,



(a) End-to-End Throughput (b) End-to-End Delay (c) End-to-End Jitter

FIGURE 25. SDN flow scheduling - performance results.

the latter uniformly distributed in [0.01, 0.1] seconds. Flows are from real traffic traces [27].

In fig. 25 flows 1-21 are file sharing, flows 22-36 are tele audio, and flows 37-45 are video streaming. For file sharing flows, the load balance algorithm outperforms the bin packing algorithm, while our proposed algorithm has an average 8% throughput increase if compared with the load balance algorithm. The reason is in wireless links when link utilization exceeds a threshold, the packet drop rate increases dramatically. Figure 25 (b) shows that for tele audio flows, our proposed algorithm can improve the end-to-end delay performance by 51% and 71%, compared to load balance and bin packing algorithm respectively. However, the other two types of flows suffer approximately the same delay experience under these three algorithms. We argue the reason is tele audio flows have bursty traffic patterns; it might not have big data volume, but if two flows are scheduled with similar busty pattern in the same link, a large delay occurs. That is why tele audio flows have poor delay performance under bin packing and load balance algorithms. Figure 25 (c) shows that video streaming flows have an average 32% and 67% less jitter with our proposed algorithm than the other two algorithms. Two observations can be obtained here, again pushing for inter-disciplinary considerations and optimizations, as well as towards dynamic optimization management also based on application awareness: a) video streaming flows have a better overall jitter performance than tele audio ones; b) our proposed algorithm has almost the same throughput and delay performance on video streaming flows, compared with the other two algorithms. The reason is video streaming flows have variable packet length, but almost constant inter packet interval. Hence if the interfered flows also have a stable inter packet interval, the jitter should be low. In fact, our proposed algorithm schedules more video streaming flows with flow sharing flows (more stable inter packet interval) than tele audio flows (variable inter packet interval).

VII. DEVICE TO CLOUD INFRASTRUCTURE FOR THE SMART GRID

The interdisciplinary research described in this work represents a long journey that is currently converging in Arrowhead Artemis project. This journey inspired the device to cloud (D2C), a new approach for the monitoring, management and effective use of the SG in a Electro Mobility industrial scenario. M2M and IoT follow a common technological paradigm: intelligent devices, seamlessly connected to the Internet, enable remote services and provide actionable data. One of the most important aspects of the IoT vision is that smart objects communicate effectively with each other and with applications residing in data centers or on the cloud. In this context, the concept of D2C proposes an end-to-end solution that includes purpose-built hardware, a pervasive framework for data acquisition, connectivity management, device management and a set of M2M cloud-based services. The objective of this solution is to deliver actionable data from the SG to downstream applications, business processes, dashboards and reports. The concept of D2C is fundamental for the SG because for todays business it is increasingly important to have constant visibility of assets and processes, anytime and anywhere. The Arrowhead project focuses on making systems interoperable, and the Arrowhead Framework offers all the receipts to design, implement and deploy SOA embedded distributed systems and system of systems. The Arrowhead Framework enables the users to work in a common unified approach, leading towards high levels of interoperability. The D2C infrastructure proposed in Arrowhead project, offers the technical building blocks required to assemble the SG, a distributed systems of devices and sensors which must be effectively connected to IT infrastructures. This solution dramatically accelerates the time to market of M2M/IoT projects and enables future potential customers to layer their added-value components on a reliable ready-to-use infrastructure. The Arrowhead Electro Mobility Scenario introduces an end-to-end solution for the management of a SG composed by a heterogeneous recharge infrastructure for electric vehicles. Adopting a D2C approach and exploiting the potentialities of the Arrowhead Framework, the solution provides monitoring and remote management of charging station, electric vehicles recharges, optimized booking of recharges and analytics support (Figure 26).

The ICT infrastructure of the scenario is based on two subsystems: the Booking system and the Monitoring system.

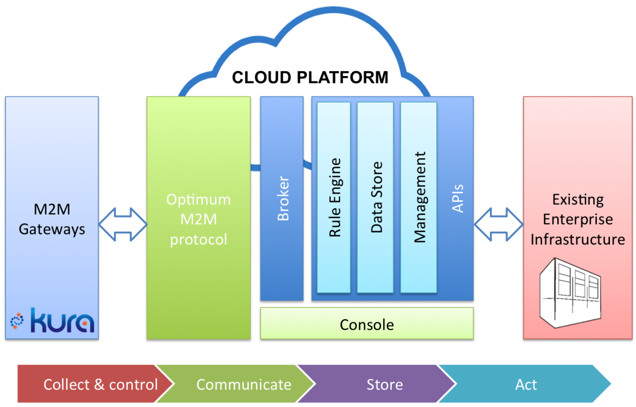


FIGURE 26. Architecture of the cloud platform.

In both cases the results achieved in previous experiences in terms of machine interpretability of semantic information suggested the use of a semantic knowledge base to provide services with context awareness over the whole information space relevant to them. Other Arrowhead services are consumed depending on the specific application. The D2C infrastructure is based on a pervasive framework (PF) and on a cloud platform (CP), which offer the technical building blocks required to integrate the ICT part of the SG. This solution is based on a combination of hardware, firmware, operating systems and programming frameworks. The (PF) is based on Eurotechs Kura, an open source IoT pervasive software framework for embedded systems that aims at offering a Java/OSGi-based container for M2M applications running in service gateways. The PF is a programming environment that hides the complexity of low level device management with high level constructs, allowing simpler and faster programming, with transparent portability across different hardware platforms: these are key elements for the adoption of the D2C paradigm. The PF specifies all aspects of the required software stack, including: device bootloader/BIOS, operating system, java Virtual Machine, OSGi application framework and an extensive set of ready-to-use plug-ins provided for specific hardware, network, cellular, and storage applications. The developer can access the core functionalities of the PF through five APIs: hardware, device configuration management, system logger, network management and IP networking. As project requirements expand beyond the core functionalities, the PF offers targeted vertical market APIs that can provide additional functions and features: GPS location tracking, mobile asset management, Industrial Protocol Communication (e.g. Modbus, CanBus), MQTT publish/subscribe broker technology, cloud-based asset and data management, etc.. This abstraction layer is the first level of abstraction of the embedded system. More high-level and application oriented abstraction layers are provided in form of services that simplify and speed-up the software development: I/O services, data services for telemetry, cloud services, configuration services, policy-driven publish and subscribe services, networking services, remote management services, web services, etc.. The cloud platform (CP) is a M2M integration platform that simplifies SG device and data management by connecting distributed devices over secure and reliable cloud services. It is an end-to-end platform that provides an easy path to connect cloud-ready devices to IT systems and/or applications. Once devices are deployed, the cloud platform allows users to connect, configure and manage devices through the entire lifecycle, from deployment, through maintenance, to retirement. The CP offers a service abstraction that provides, with a simple service model, full control over the SG embedded systems hardware, software and acquired data. The objective is to hide the complex details that stand behind the remote management procedures, remote data acquisition and transmission. Figure 27 illustrates the architecture of the cloud platform.

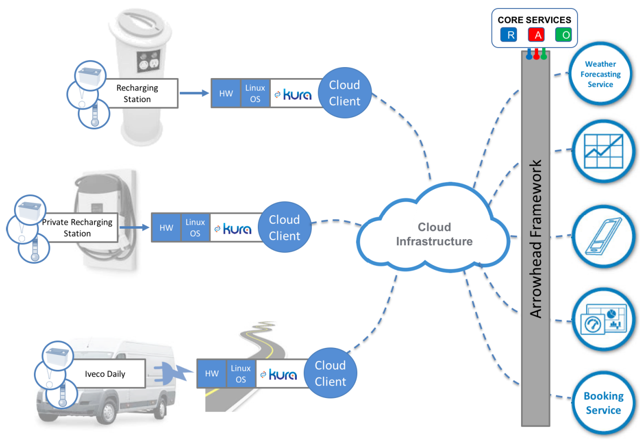


FIGURE 27. Arrowhead D2C infrastructure.

The M2M protocol represents the glue that keeps together the distributed components (sensors, charging stations, gateways, cloud, EVs etc.) of the SG. The core unit of the CP is the MQTT message broker. The Rule Engine is based on SQL and is responsible for processing incoming published data. Statistical rules are applied over the data in real-time and the actions generated by the rules can include e-mail, SMS, or Twitter notification, a field protocol publish event, or a REST API call. The CP adopts a non-SQL non-relational database for SG data storage: this solution allows managing huge amounts of data (Big Data), facilitating the integration with existing enterprise infrastructure. Through the management unit, the CP provides the second level of abstraction of the D2C approach: this abstraction layer introduces a set of services that simplify, directly from the cloud, data collection, device monitoring, data management, account management, application development, etc.. The service abstraction cooperates with the PF to completely hide the complexity of hardware, communications and cloud infrastructure. The CP data model allows describing functional and extra functional properties of the SG in the cloud using two types of topics: publish topic and control topic. Publish topics are used by a device (or application) to publish data into the CP, while control topic are used by the application or the platform to send data to a node of the SG. Finally, the cloud abstraction layer is based on a publish-subscribe-notify paradigm that allows the separation of data producers and data consumers and the creation of one-to-many message distribution.

VIII. CONCLUSION

The integration between electro-mobility and the urban power distribution network requires careful, simulation based, pre-deployment analysis of the recharging infrastructure and of the associated services. It then converges into a multi-internet and multi-platform infrastructure. The sustainability and the benefits of the resulting ecosystem are strictly related to the appropriate handling of requirements related to user satisfaction, energy efficiency, communication and power network qualities, which can be satisfied only if the dynamic interplay between several vectors are considered: EV penetration, associated travel, traffic and recharging patterns, power, density and distribution of recharging spots, RESs and energy storage units, user services, user behaviour prediction, control capabilities of the power delivered by the power network feeders and business models of the entire value chain. Such a multivariate scenario leverages on the research results of large multidisciplinary teams that join forces towards this key enabler of sustainable development. This paper focused on information management and communication, co-simulation frameworks and services for the smart grid.

Each of these topics has brought together researchers from different areas, departments and sectors. For example in order to create the co-simulation framework for pre-deployment analysis of recharging infrastructures and services PhD students in information science, senior researchers from the European automotive and infrastructure industry level (FCA and SIEMENS), worked together within the framework of large projects reinforced by the catalytic action of the smart energy system action line of EIT Digital. In this way the resulting Electro Mobility and power network co-simulation framework allowed i) to ground the proposed services to realistic data and traffic patterns and ii) to size the SG infrastructures and power distribution facilities, according to different market penetrations of electric mobility, as well as to calculate the impact on the traffic and on the power grid of novel mobile services. In turn the vision described in section V about mobile and user centric services required the joint research of mobile systems researchers, automotive experts, service oriented architectures, semantic interoperability and electrical engineering experts, matching the requirements both from the user and the grid sides, to be verified by the co-simulation framework. Eventually the activity on the communication and information management infrastructure brought together researchers from the embedded systems industry with academic cloud computing and semantic technologies experts, very much in line with the emerging internet of things vision. Here the purpose was to enble the smart grid to leverage on research in architectures and algorithmic solutions related to software defined networking. Likewise, from the point of view of semantic interoperability and big data management a cloud based infrastructure has been identified together with a device to cloud infrastructure, to support the interaction of the smart grid with cloud based services.

Even if the smart grid has been considered only from the point of view of its interplay with electro-mobility, the smart grid vision proposed and its relevance in sustainable development demonstrate the emerging need for interdisciplinary infrastructures and approaches in research and education.

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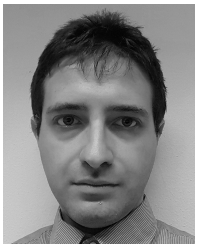

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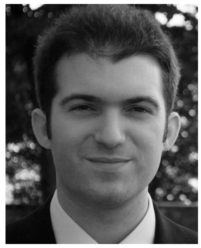

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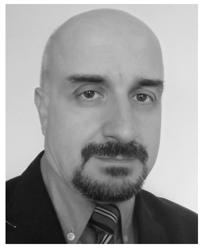

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