Modeling Virtual Sensors for Electric Vehicle Charge Services

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***Abstract*—This paper proposes innovative services in the electromobility framework with the goal of enhancing the electric vehicle charging experience. In this context, the objective is to provide a smart charging service that helps drivers to make the best choice for charging their electric vehicles, according to the vehicle real-time position, battery type and autonomy. Moreover, the drivers are allowed to book the preferred charge option according to availability and cost of the charge points. To this purpose, two virtual sensors are designed and defined that allow to perform the smart charging searching service. In particular, an algorithm and a UML diagram are adopted to describe the virtual sensors operations and cooperation. In addition, the proposed virtual sensors functioning and interactions are described as Discrete Event Systems modeled in a Petri Net framework.**

***Index Terms*—Electric Mobility, Virtual Sensor, Petri Net, Unified Modeling Language**

I. INTRODUCTION

In recent years a new trend is emerging in the transport sector that moves towards the adoption of green and zero-emission transport means. In the European context, cities administrators are dealing with serious issues due to the congestion of public roads, caused by the increasing urban population and the resulting massive usage of conventionally-fueled vehicles. In this framework, the main objectives are to solve the issues of emissions, noise pollution and urban air quality. To reach these goals, one of the objective of the European Commission is to overcome the use of conventional Internal Combustion Engine Vehicles (ICEVs) in cities by 2050, and to guarantee a better quality of life and health for European citizens. Therefore, Electric Vehicles (EVs) are promoted as an alternative to the ICEVs, even though they still have a more limited driving range and need to access specific charging points (CPs). Moreover, recent studies demonstrates the increasing attention of researchers towards the EV frameworks and markets [1] - [9]. The authors in [1] and [3] propose a classification of the stakeholders in the electromobility domain, defining and modeling their functions and interactions. Moreover, in [3] the authors analyze the critical challenges of the electric mobility and propose a conceptual model of electric vehicles ecosystem. There are technical challenges related to the vehicles and the battery technology, e.g. the battery life cycle and the manufacturing process. Furthermore, other challenges refer to the adoption of new policies for the EV control and management, taxation strategies and market dynamics. In addition, the lack of interoperability between eRoaming platforms as well as of the standardization of infrastructure and services are remarked by the authors in [1], [3]. Some authors propose strategies to estimate EV parameters and manage battery technology, vehicle control, charging and power grid issues [4] - [10]. In particular, the authors in [4] provides a review and classification of the estimation techniques and strategies for hybrid and electric vehicles, pointing out that estimation of any fault, state or information plays an important role in ensuring vehicles stability and reliability. Indeed, considering the cost of sensing devices and, in some cases, the practice difficulty to measure some key parameters by physical sensors, estimation is becoming necessary to monitor and control vehicle parameters.

This paper introduces Virtual Sensors (VSs) that operate in the sensor-cloud platform as abstraction of the physical devices [11]. A VS reproduces one or more physical sensors from the logical point of view, improving and increasing their functions, being able of performing complex tasks that cannot be accomplished by physical sensors [11]. More specifically, a VS is seen as a specialized service that derives new data or information from existing and available data by physical sensors. It encapsulates a data processing algorithm to obtain the required output by elaborating the data inputs. VSs are deployed in different research fields such as healthcare, energy, mobility, etc., to compute or estimate parameters values from the distributed physical instrumentation measurements [12].

In particular, this paper analyzes the VSs adoption in the field of electromobility and proposes innovative services, mainly related to the charge planning of an EV. To this purpose, two VSs are designed devoted to the intelligent research of CPs on the basis of vehicle status, charge cost and driver preferences. In particular, a first VS is devoted to the estimation of the CPs availability in the neighborhood of the given EV. Moreover, a second VS is adopted to compute the charge session cost and eventually book the preferred charge

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station. Thanks to the proposed VSs, the EV driver is capable to plan the CP stops during its trip, taking into account both EV battery charge needs and user trip requirements. The VSs algorithms are described and modelled by means of a Unified Modeling Language(UML) diagram [13].

In order to describe the use of the proposed VS services, we model the VSs functioning in a Timed Petri Net (TPN) framework [15]. Indeed, the PN has twofold features, graphical and mathematical, allow modeling and simulating complex systems also in the field of transportation: for instance car sharing systems [18], Hazmat Transportation [17] and intermodal transportation systems [16].

It is remarked that this paper is written in the framework of the European Union Horizon 2020 project NeMo - Hyper-Network for electromobility, which aims at creating a hypernetwork of new and existing tools, models and services [14].

The rest of the paper is structured as follows. Section II gives a definition of VSs as a service. Section III proposes the VSs for the electromobility and Section IV describes in detail the VSs for charge point availability, cost and booking determination. Finally, Section V propose the conclusions and some perspectives on future works.

II. VIRTUAL SENSOR AS A BUSINESS SERVICE

In the context of business market for advanced and complex services, there is an increasing need of using common standards for defining data formats, data exchange, communication framework in order to facilitate and accelerate service deployments, service integrations and facilitate innovative service definitions. Business developers need to start from high level components that are easy to use, easy to integrate with legacy software and easy to reuse to create novel complex services. To this aim, a common framework for the definition and the execution of the services has to be developed. This common framework typically is build up starting from the definition of a Common Data Format (CDF), a common service definition methodology and a common invocation procedure. The Common Data Format can be used by developers to cope with interoperability issue among new services and legacy systems.

More generally, a Service can be modeled using Business process modeling (BPM) [2]. BPM is the activity of representing processes of an enterprise, so that each process can be analyzed, modified and automated. BPM is typically performed by business analysts, who provide expertise in the modeling discipline. Using such high level BPM modeling, the business objective is often to reduce process developing time, to increase quality and to reduce costs, such as labour, materials, scrap, or capital costs. Moreover, it helps developing change management programs. They are typically involved to put any improved business processes into practice.

Different basic roles can be defined for the basic building blocks for service implementation:

- Sensor service: this type of service provides as output the value of a given physical sensor;
- Actuator service: this type of service requires as input the value to be applied to an actuator, and the result is the application to the actuator;
- Virtual Sensor service: this type of service provides as output an estimation of a data using as input other data sources; the estimation is typically a prediction computed using suited predictive models;
- Simple service: this type of service has simple inputs and simple outputs;
- Complex service: this type of service performs a huge amount of computation and can reuse output from services of the previous categories.

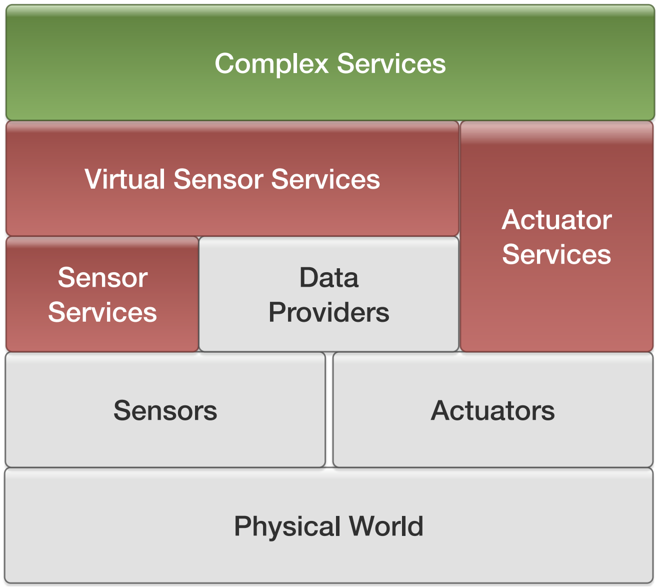

Fig. 1. Business Service Development Stack.

Fig. 1 presents the Business Service Development Stack considered as reference for the definition of Complex Service. In this context, a VS Service is defined as a sensor that gather data form external data sources and infer the new data provided as output by using predictive models. Such VSs are increasing they role in the business market as:

- the amount of data acquired by physical operator is increasing;
- the algorithms to manage such big data streams are complex due to management of data origin, data privacy, data protection, etc.;
- the systems to perform such elaboration are complex.

A VS can perform such operation and it can be used as a building block for generating complex services. In the following we present two different VS service and how to connect them to create a complex service.

III. VIRTUAL SENSORS FOR ELECTROMOBILITY

In this section, two VSs that cooperate to provide innovative EV charging services are described. First, a VS, called VS1, devoted to search and find available charge points in the driver neighborhood area is presented. A second VS, so called VS2, determines the cost to charge the EV at each CP of the selected area and allows the driver to choose the preferred charge option. Both VS and their operations are described by two different algorithms that cooperate to provide the final service. Moreover, a UML sequence diagram is designed to show the interactions between VS1-VS2 and other actors in the electromobility domain.

A. VS1: Charge Point Availability

In this section, the VS1 to determine the availability of CPs in a specific area for charging the specific EV, is presented. The VS1 operations are described by means of an algorithm and a UML sequence diagram (see Fig. 2). In particular, the VS1 analyses the CPs availability in the driver's neighborhood in a specific time horizon and provides the list of CPs with their geographical position and technical information.

Once a EV user requires the VS1 service, the VS1 requires GPS position of the EV that needs to charge, the battery type and charge level by the Vehicle Manufacturer back-end system. Moreover, the driver has also to select the preferred time horizon. Afterwards, the VS1 searches and finds the CPs in the neighborhood, taking into account the vehicle autonomy and battery type, and collects all the necessary information about CPs. At this point, the VS1 is able to provide the list of CPs compatible with the EV battery in the related area. It is remarked that to retrieve the necessary inputs and to accomplish its tasks, the VS needs to interact with different actors in the electromobility domain such as the Charge Point Operator (CPO), IT cloud platform provider, map service provider, EV manufacturer and the driver [1], as depicted in Fig. 2).

1) Inputs and Outputs: In particular, the following inputs are required by the VS:

- EV GPS position (latitude, longitude);
- EV residual battery charge (% or km);
- EV battery capacity and type;
- Driver time slot preference (hh.mm-hh.mm.);
- CP GPS position (latitude, longitude);
- CP occupancy status;
- CP booking requests;
- Traffic data.

The VS provides a list of CPs including the following information for each CP:

- selection range (km);
- GPS coordinates (latitude, longitude);
- Charge power (kW);
- distance (km);
- occupancy time slot (minutes);

2) Algorithm: The VS1 operates according to Algorithm 1.

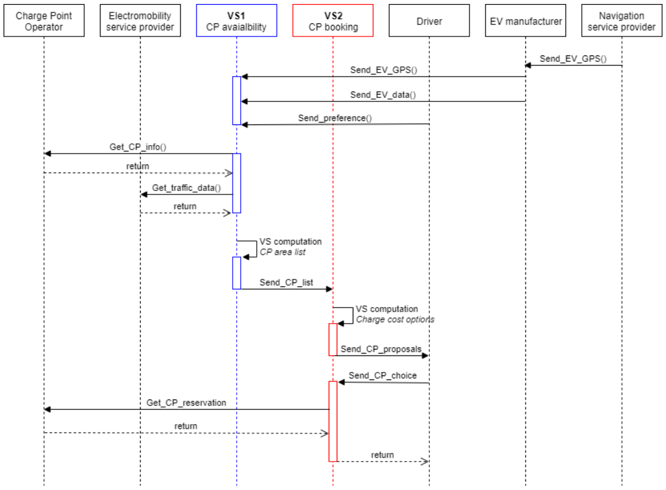

Fig. 2. The UML sequence diagram of VS1 and VS2 operations.

***Algorithm** 1:*

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1:  START.
2:  The driver asks for VS service and the vehicle sends
    the required data to VS.
3:  VS requests data to the involved actors (see Fig. 2).
4:  Actors reply to VS requests.
5:  VS computes the maximum area reachable by the EV:
    $A_{max} = GPS_{pos} + km_{res}$. Set $j = 1$,$S_A = \emptyset$.
6:  VS computes $A_j = A_{max} - K * j$. Set $j = j + 1$,
    $S_A = S_A \cup A_j$. Set $m$ cardinality of $S_A$.
7:  If $A_j \geq K$, then go to STEP 6.
8:  Set $j = 1$.
9:  Select area $A_j$.
10: VS provides the CP list in the area $\bar{A} = A_j$. Set $j = j+1$.
11: If $j \leq m$ go to Algorithm 2.
12: END.
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In addition, Fig. 2 shows the main interactions of VS1 with other actors to perform the steps of Algorithm 1.

B. VS2: Charge Point Booking

In this section, the VS that computes the charge session cost and allows to book the charge point is presented. In particular, the VS2 operations are based on the output of VS1. It considers the CPs in the selected area A_i by VS1 and computes the cost for charging the considered EV battery, based on the energy tariff and the actual charge autonomy. Two charge cost options are computed: 1) the cost to reach the complete battery charge; 2) the cost to reach the desired battery charge. User can choose the preferred charge option. Once the driver has choosen the CP and the charge option, the VS2 verifies the availability of the CP. In case the selected CP is available, the driver can book it, otherwise he/she must wait for the CP becoming free, go to another CP in A_i or go back to Algorithm 1 and select a new area.

The operations performed by VS2 are described in Algorithm 2. Furthermore, the interaction between VS2 and other actors is described in Fig. 2.

1) Inputs and Outputs: In addition to what it is needed by VS1, VS2 needs to know the desired "charge level/km autonomy" by the driver and the CPs tariff (€$/kWh$) to compute the charge session cost for the EV in each CP in the considered time horizon, in the selected area A_i.

Indeed, the VS provides a list of CPs including the following information for each CP:

- selection range (km);
- GPS coordinates (latitude, longitude);
- status (free/occupied);
- distance (km);
- CP tariff (€/kWh);
- Complete charge cost (€);
- Desired charge cost (€);

2) Algorithm: The VS2 works according to the steps of Algorithm 2.

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Algorithm 2:
1: START.
2: VS computes the unitary percentage charge cost of
   the EV battery:
   $1\%_{EV} = BatterySize/100$;
   $1\%_{EV}Cost = 1\%_{EV} * UnitaryCost$.
3: $\forall$ CP of $\bar{A}$, VS computes the complete charge cost:
   $\%Miss = 100 - \%Res$;
   $CC_{cost} = \%Miss * 1\%_{EV}Cost$.
4: $\forall$ CP of $\bar{A}$, VS computes the desired charge cost:
   $DC_{cost} = (\%DC - \%Res) * 1\%_{EV}Cost$.
5: VS adds cost options to CP list in $\bar{A}$.
6: CP is chosen/booked by the driver based on the
   availability and cost.
7: If no CP is chosen in $\bar{A}$ go to STEP 9 of Algorithm 2.
8: VS sends CP choice to other actors.
9: END.
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IV. PETRI NETS FOR VS1 AND VS2 MODELING

In this section the proposed VSs functioning and interactions are described as Discrete Event Systems in a TPN framework. In particular, places denotes the different operative conditions of the VS and transitions models the possible actions performed by the VS or the driver.

A. Background of Timed Petri Nets

A TPN [15] is a bipartite digraph described by the five-tuple $TPN = (P, T, Pre, Post, F, RS)$, where P is a set of places, T is a set of transitions partitioned into the set T_I of immediate transitions (represented by bars), the set T_E of stochastic transitions (represented by boxes) and the set T_D of deterministic timed transitions (represented by black boxes). Matrices Pre and $Post$ are the pre-incidence and the post-incidence matrices, respectively, of dimension $|P| \times |T|$. Note that we use symbol $|A|$ to denote the cardinality of the generic set A. Moreover, F is a firing time vector. The firing times of transitions can be exponentially distributed random variables. The transition $t_j \in T_E$ with exponentially distributed firing times are described by the mean value $F_j = \delta_j$ (i.e., the j-th element of vector F). In addition, each $t_j \in T_I$ has zero firing time, i.e., $F_j = 0$ and the generic transition $t_j \in T_D$ is associated with the constant firing delay $F_j = \delta_j$. Finally, $RS : T \to R^+$ is a function that associates a probability value called random switch to conflicting transitions. The state of a TPN is given by its current marking, which is a mapping $M : P \to N$, where N is the set of non-negative integers. M is described by a $|P|$-vector and the i-th component of M, indicated with $M(p_i)$, represents the number of tokens in the i-th place $p_i \in P$. A TPN system $\langle PN, M_0 \rangle$ is a TPN with initial marking M_0. A transition $t_j \in T$ is enabled at a marking M if and only if for each $p_i \in P$ such that $Pre(p,t) > 0$ it holds $M(p_i) > 0$. When fired, t_j determines a new marking M_{new}, where for each $p_i \in P$ it holds $M_{new}(p_i) = M(p_i) + Post(p_i, t_j) - Pre(p_i, t_j)$.

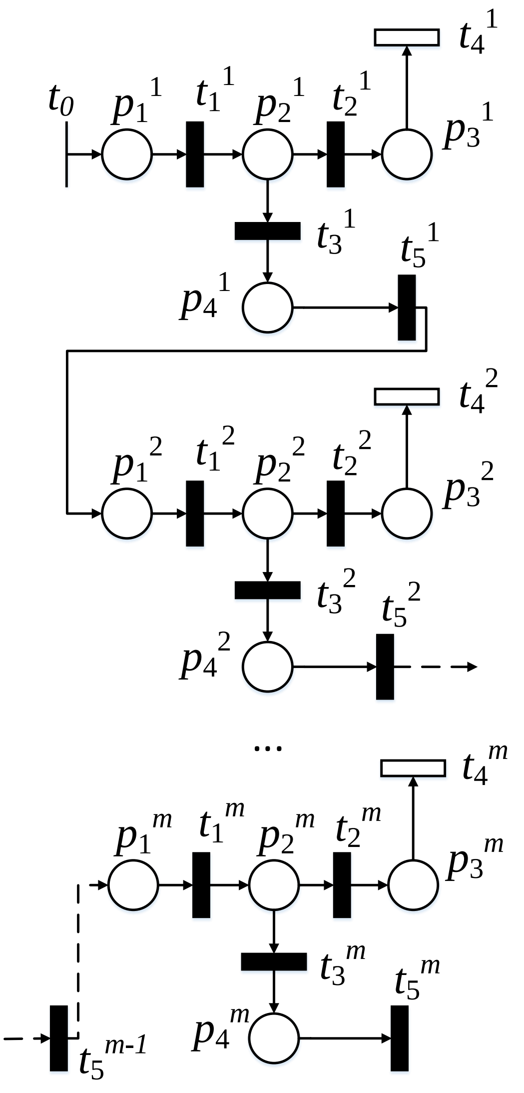

Fig. 3. The scenario for the use of VS1 in a PN framework.

B. PN for VS1 implementation scenario

In this subsection, the use of the VS1 service by an EV driver is modeled by means of the PN shown in Fig. 3. We denote with $m = |S_A|$ the number of selected areas based on the GPS position of the EV. Each transition t_i^j (place p_i^j) is referred to the event (state) i occurring in the area A_j, while the immediate transition $t_0 \in T_I$ is the starting transition that models the driver request of VS1 service.

TABLE I
PLACE MEANINGS IN THE AREA A_j OF VS1

Place	Description
p_1^j	VS1 is operative
p_2^j	VS1 is on standby waiting EV driver decision
p_3^j	EV is charging its battery
p_4^j	The new area A_{j+1} is chosen by the EV driver

TABLE II
TRANSITION MEANINGS IN THE AREA A_j OF VS1

Transition	Description	δ_i^j
$t_0 \in T_I$	VS1 service is requested	0.0
$t_1^j \in T_D$	CP list of A_j is trasmitted to VS2	0.1
$t_2^j \in T_D$	The driver decides to charge the EV in area A_j	syn
$t_3^j \in T_D$	The driver decides to change area	syn
$t_4^j \in T_E$	The EV charging is completed	syn
$t_5^j \in T_D$	VS1 returns to be operative for the area A_{j+1}	0.1

When t_0 fires, VS1 is operative (place p_1^1 marked): it communicates with the involved actors, calculates the m areas and determines the n CPs in the area A_1, i.e. the area nearest to the EV driver. The information about the CP list of A_1 is transmitted to the VS2 (transition t_1^1 fires) and VS1 is on standby (place p_2^1 marked) waiting the EV driver decision. If the EV driver, assisted by the VS2, decides to charge the vehicle in a CP of A_1 then transition t_2^1 fires and the EV starts to be charged (place p_3^1). When the EV charging is completed, transition t_4^1 fires. Otherwise, if the driver finds the CPs of A_1 not available or not convenient, then transition t_3^1 fires. Now, the VS1 returns to be operative (transition t_5^1 fires and p_1^2 is marked) and determines the CP list in the area A_2 to be transmitted to VS2.

The process for the areas A_2, A_3, …, A_m is exactly the same of A_1. However, in the area A_m, if the EV driver decides to not charge the vehicle, the assistance of the VS1 ends (transition t_5^m fires) and the driver has to perform a new request.

In this case, all the transitions are assumed deterministic or immediate, except the transitions t_4^j with $j = 1, \ldots m$ that are supposed stochastic. This is due to the fact that the mean value $\delta_4^j \gg \delta_i^j$ with $i = 1, \ldots 5$ and $i \neq 4$. Moreover, the duration time of the EV charging is inherently stochastic, because it can considerably change on the basis of the EV battery level.

Table I and II summarize, respectively, the meaning of places and transitions. In particular, Table II highlights the mean values in minutes of the transitions. However, the firings of transitions t_2^j, t_3^j and t_4^j depend and are synchronized (we indicate it with "syn") with some transitions of VS2 that regulates the EV booking and charging.

C. PN for VS2 implementation scenario

In this subsection, we describe the use of the VS2 service modeled by the PN shown in Fig. 4. The VS2 becomes operative when VS1 transmits to it the list of n CPs of a generic area A_j with $j = 1, \ldots, m$ and the data of the EV driver. The immediate transition $t_{01} \in T_I$ models the arrival of the data from VS1 to VS2. Hence, p_{01} is marked when all the data are available. Now, the VS2 is ready for the data processing (transition $t_{02} \in T_D$ fires and p_{02} is marked). The VS2 determines the charging costs of each CP in the area and transmits them to the EV driver (transition $t_{03} \in T_D$ fires and p_{03} is marked).

Now, the EV driver can choose the preferred CP on the basis of the data received by the VS2 (one of the transition t_1^i with $i = 1, \ldots n$ fires) or can decide to change area (transition t_{04} fires). Naturally, the transition t_{04} of VS2 is synchronized with the transition t_3^j of VS1.

Without loss of generality, we assume that the EV driver chooses the first CP (transition t_1^1 fires and place p_1^1 is marked). In this case, two possibilities can occur: *i*) the CP is available (place p_2^1 is not marked and place p_3^1 is marked); *ii*) the CP is not available (place p_2^1 is marked and place p_3^1 is not marked).

- *i*) The vehicle starts its charging in the first CP. Indeed, only the transition t_2^1 is enabled and fires putting one token in the place p_2^1 and emptying the place p_3^1. The transition t_2^1 of VS2 is naturally synchronized with the transition t_2^j of the VS1. When the EV charging is completed, then transition t_6^1 fires emptying place p_2^1 and marking newly place p_3^1.
- *ii*) The vehicle cannot start its charging because the CP is occupied. In this case, the EV driver can choose if waiting the charging end (transition t_3^1 fires) or coming back to choose a new CP or change area (transition t_4^1 fires). If the EV driver decides to wait the availability of the CP, the place p_4^1 is marked, but the transition t_5^1 is not enabled because p_3^1 is empty. However, when the CP comes back to be available, the transition t_6^1 fires and p_3^1 is marked. In this case t_5^1 is enabled and the driver can start the EV charging (t_5^1 fires).

Obviously, the enabled transition t_6^i with $i = 1, \ldots n$ is synchronized with the corresponding transition t_4^j with $j = 1, \ldots, m$ of the VS1.

As in the case of VS1, we assume stochastic only the transitions t_6^i, because they have a mean value $\delta_6^i \gg \delta_k^i$ with $k = 1, \ldots 5$ and $\delta_6^i \gg \delta_{0k}$ with $k = 1, \ldots 4$. Moreover, the duration time δ_6^i can be considered stochastic because it changes on the basis of the EV battery level.

Table III and Table IV summarize the description of the meanings of places and transitions of the VS2 model.

V. CONCLUSION

This paper proposes innovative services to facilitate the electric vehicle smart charging. To this aim, two virtual sensors (VSs) are presented, devoted to the charge station finding and booking and the charge cost determination. In particular, the VSs operations are described by means of two algorithms and the interactions between the VSs and the electromobiliy stakeholders are represented by a UML sequence diagram. Moreover, the VSs functions are described in a Petri Net framework.

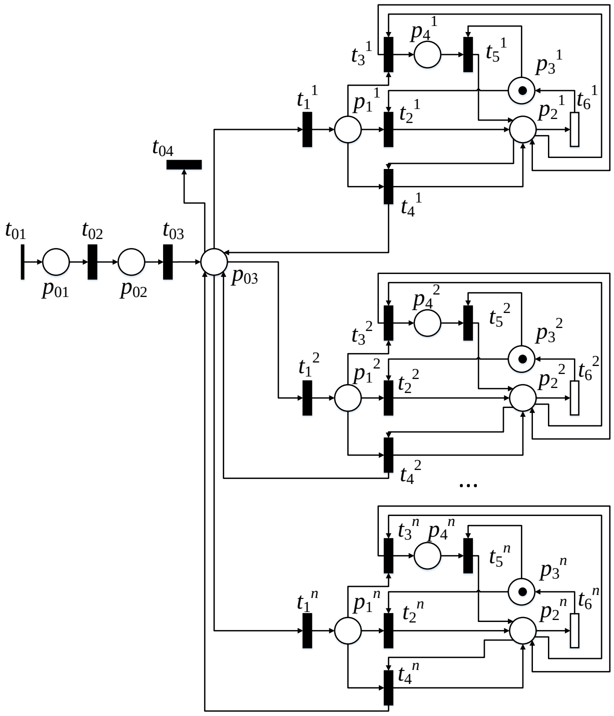

Fig. 4. The scenario for the use of VS2 in a PN framework.

TABLE III
PLACE MEANINGS IN THE PN OF VS2

Place	Description
p_{01}	All needs data of VS1 are received by VS2
p_{02}	VS2 is operative (CP cost calculation)
p_{03}	The CP charging costs are trasmitted to the EV driver
p_1^i	The driver decides to charge the EV in CP_i
p_2^i	The CP_i is occupied
p_3^i	The CP_i is available
p_4^i	The EV driver decides to wait the CP_i availability

TABLE IV
TRANSITION MEANINGS IN THE PN OF VS2

Transition	Description	δ_i^j
$t_{01} \in T_I$	VS1 data are received by VS2	0.0
$t_{02} \in T_D$	VS2 calculates the charging costs	1.0
$t_{03} \in T_D$	VS2 trasmits the charging costs to the EV driver	0.1
$t_{04} \in T_D$	EV driver decides to change area	3.0
$t_1^i \in T_D$	The driver chooses to charge the EV in CP_i	3.0
$t_2^i \in T_D$	The EV starts its charging in CP_i	2.0
$t_3^i \in T_D$	The driver decides to wait the CP_i availability	1.5
$t_4^i \in T_D$	The driver decides to choose another CP_i or to change area	1.5
$t_5^i \in T_D$	EV starts its charging in CP_i after the wait	2.0
$t_6^i \in T_E$	The EV charging is completed in CP_i	60.0

Future works will define suitable indices in order to verify the VS performances and the PN models will be simulated in specific scenarios. Moreover, new services will be proposed to enhance the EV usage.

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